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(12) **United States Patent**  
**Choi et al.**

(10) **Patent No.:** **US 10,026,736 B2**  
(45) **Date of Patent:** **Jul. 17, 2018**

(54) **SEMICONDUCTOR DEVICES AND METHODS OF MANUFACTURING THE SAME**

*H01L 29/165* (2006.01)  
*H01L 29/78* (2006.01)  
(Continued)

(71) Applicant: **Samsung Electronics Co., Ltd.**,  
Suwon-si, Gyeonggi-do (KR)

(52) **U.S. Cl.**  
CPC ... *H01L 27/0886* (2013.01); *H01L 21/02636* (2013.01); *H01L 21/823418* (2013.01); *H01L 21/823431* (2013.01); *H01L 21/823437* (2013.01); *H01L 21/823814* (2013.01); *H01L 21/823821* (2013.01); *H01L 21/823864* (2013.01); *H01L 23/26* (2013.01); *H01L 27/0924* (2013.01); *H01L 29/0847* (2013.01); *H01L 29/16* (2013.01); *H01L 29/161* (2013.01); *H01L 29/165* (2013.01); *H01L 29/1608* (2013.01); *H01L 29/6656* (2013.01); *H01L 29/66545* (2013.01); *H01L 29/66636* (2013.01); *H01L 29/7848* (2013.01); *H01L 29/7851* (2013.01)

(72) Inventors: **Sung-Hyun Choi**, Suwon-si (KR); **Yong-Suk Tak**, Seoul (KR); **Gi-Gwan Park**, Hwaseong-si (KR); **Bon-Young Koo**, Suwon-si (KR); **Ki-Yeon Park**, Hwaseong-si (KR); **Won-Oh Seo**, Incheon (KR)

(73) Assignee: **Samsung Electronics Co., Ltd.**,  
Gyeonggi-do (KR)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(58) **Field of Classification Search**  
None  
See application file for complete search history.

(21) Appl. No.: **15/384,834**

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(22) Filed: **Dec. 20, 2016**

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(65) **Prior Publication Data**

US 2017/0200718 A1 Jul. 13, 2017

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(30) **Foreign Application Priority Data**

Jan. 11, 2016 (KR) ..... 10-2016-0003213

*Primary Examiner* — Benjamin Sandvik  
(74) *Attorney, Agent, or Firm* — Harness, Dickey & Pierce, P.L.C.

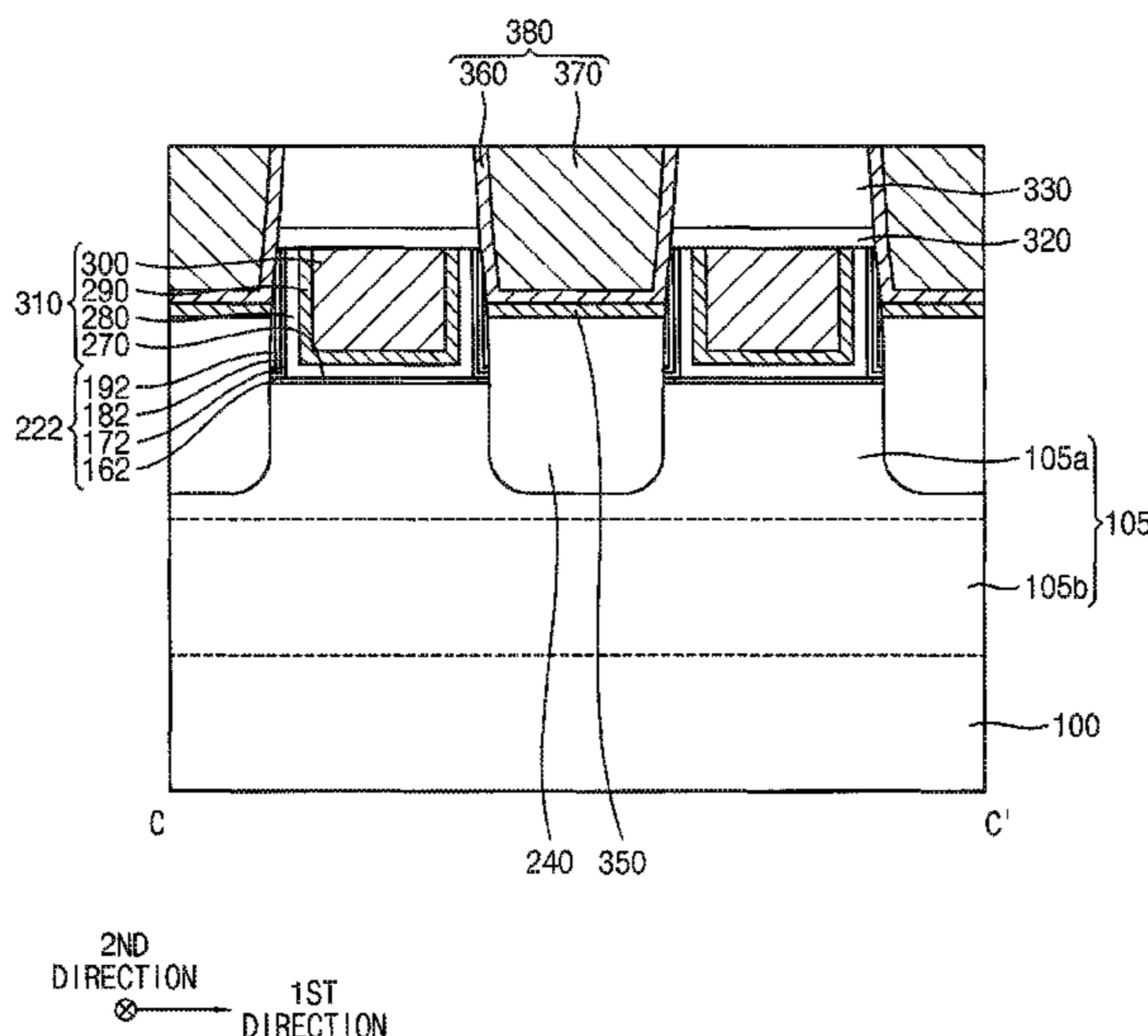
(51) **Int. Cl.**

*H01L 29/66* (2006.01)  
*H01L 27/088* (2006.01)  
*H01L 21/02* (2006.01)  
*H01L 21/8234* (2006.01)  
*H01L 23/26* (2006.01)  
*H01L 29/08* (2006.01)  
*H01L 29/16* (2006.01)  
*H01L 29/161* (2006.01)

(57) **ABSTRACT**

A semiconductor device includes an active fin on a substrate, a gate structure on the active fin, a gate spacer structure on a sidewall of the gate structure, and a source/drain layer on at least a portion of the active fin adjacent the gate spacer structure. The gate spacer structure includes a wet etch stop pattern, an oxygen-containing silicon pattern, and an out-gassing prevention pattern sequentially stacked.

**14 Claims, 66 Drawing Sheets**



- (51) **Int. Cl.**  
*H01L 21/8238* (2006.01)  
*H01L 27/092* (2006.01)

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FIG. 1

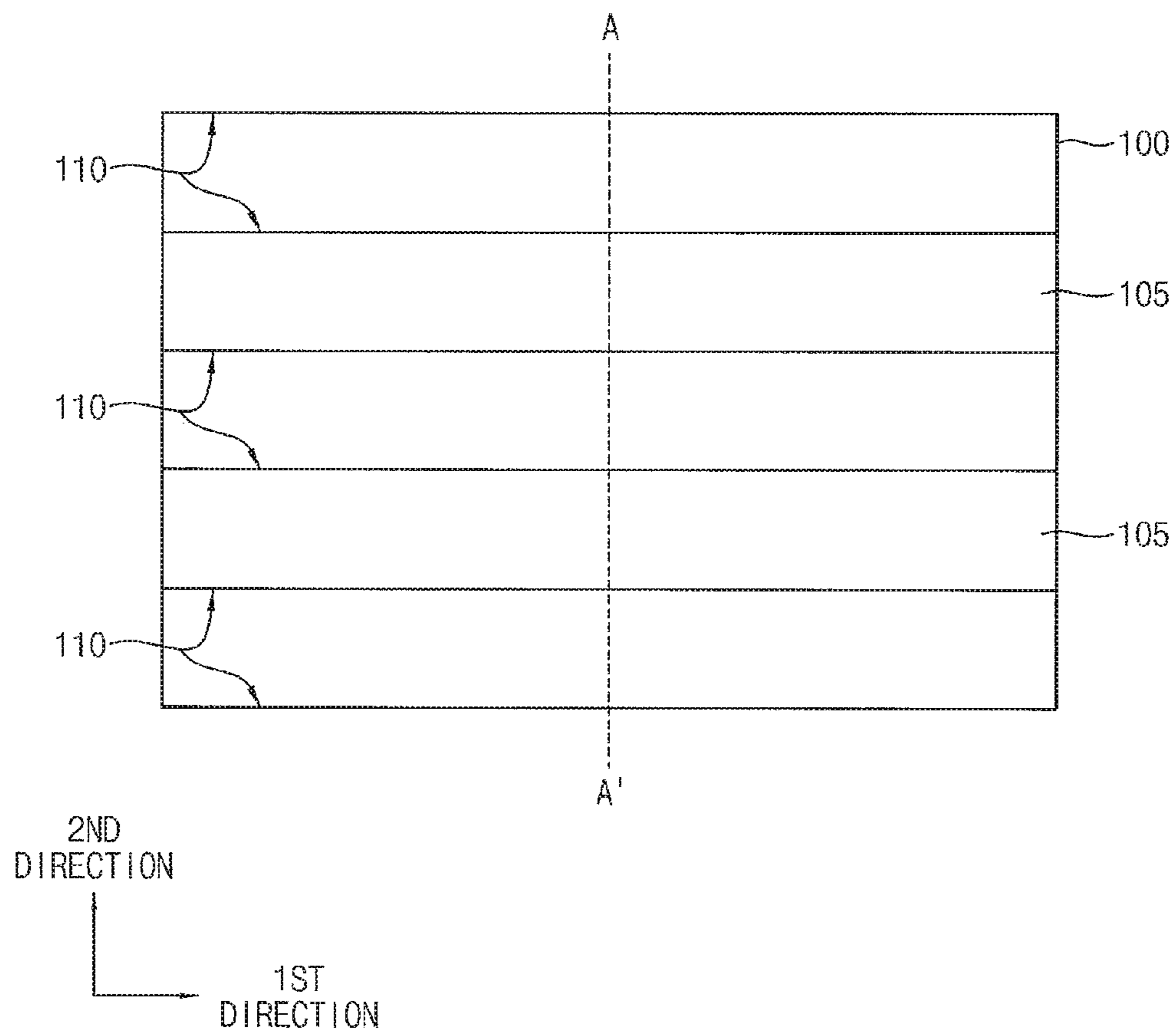


FIG. 2

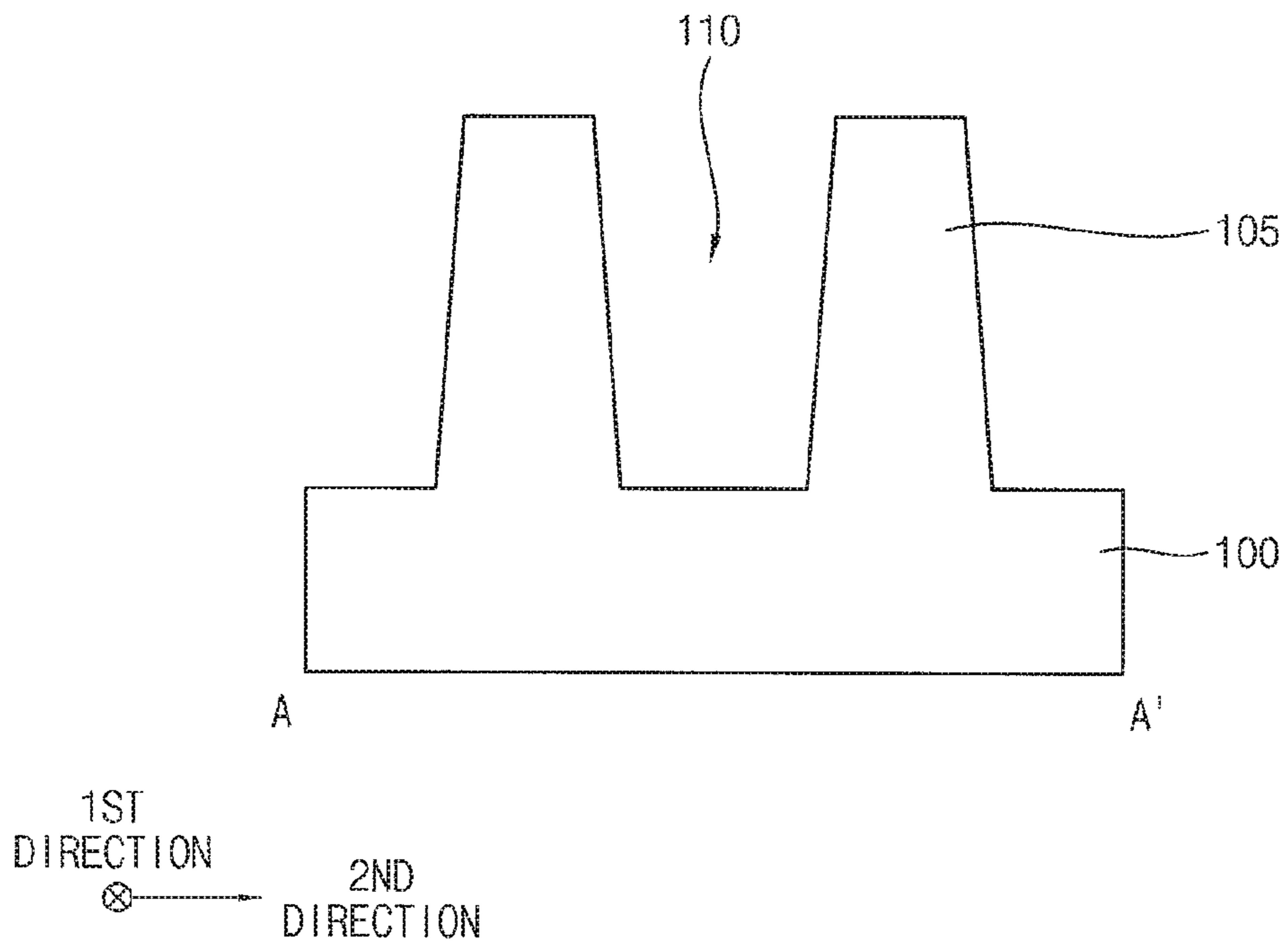


FIG. 3

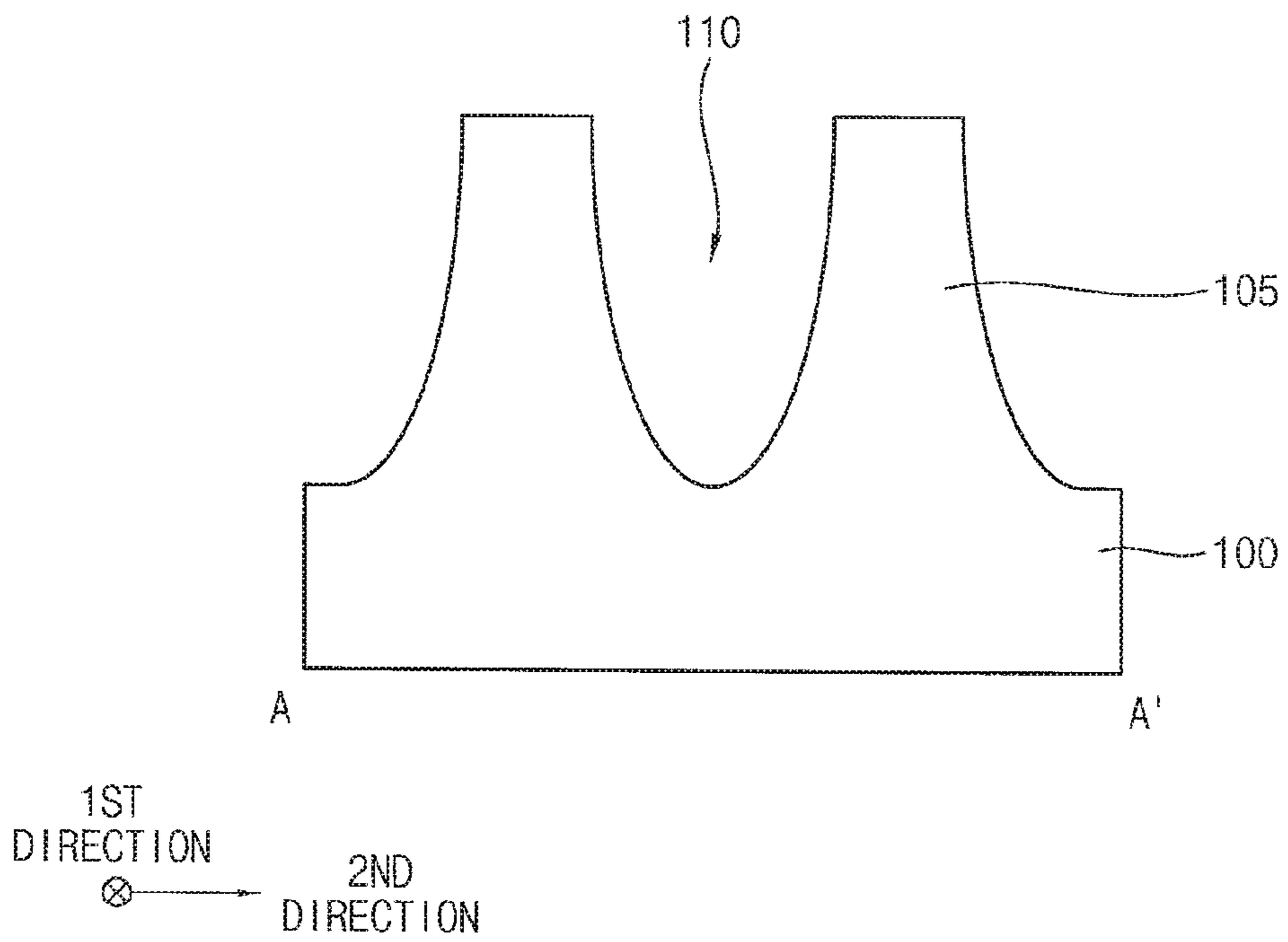


FIG. 4

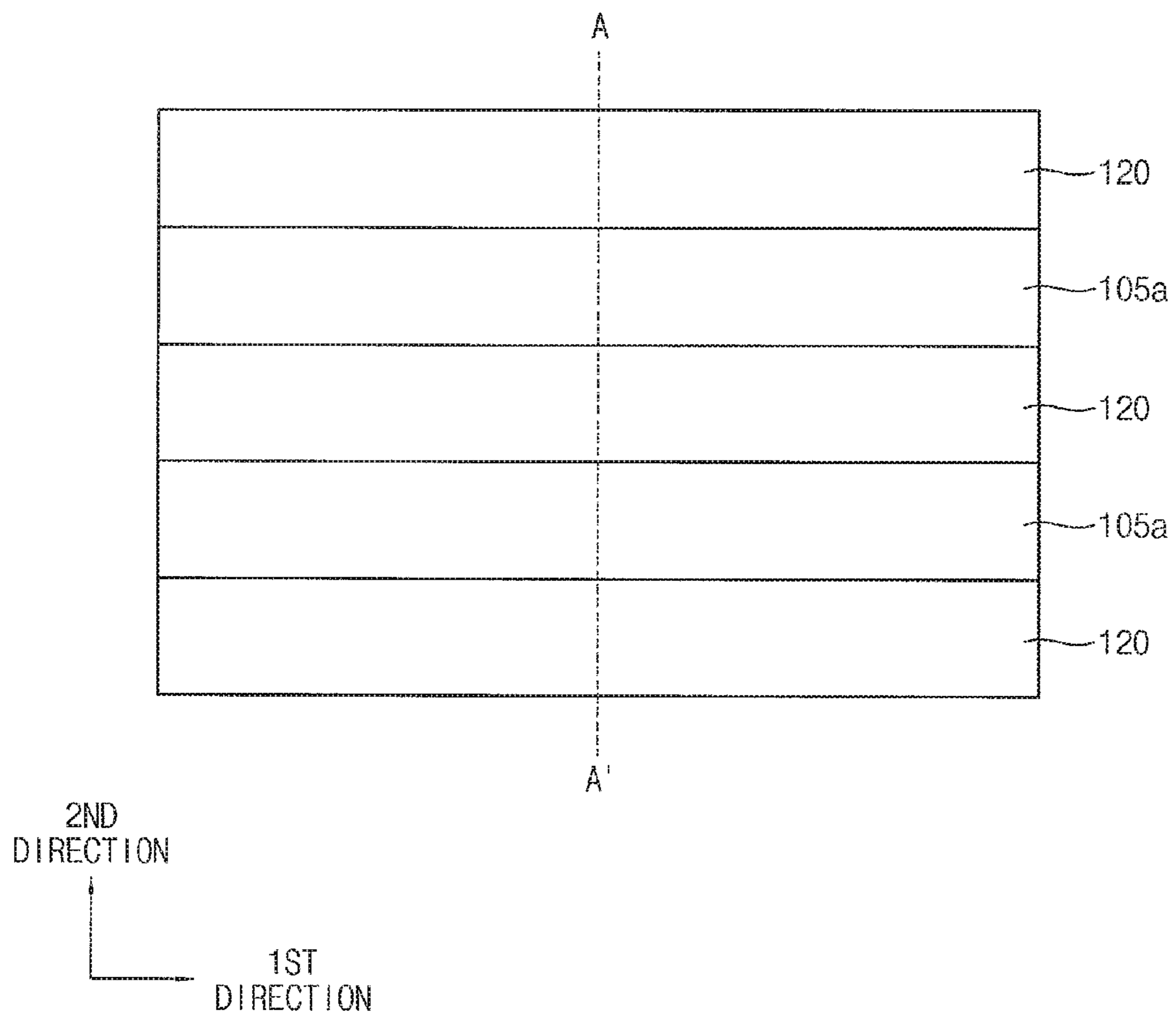


FIG. 5

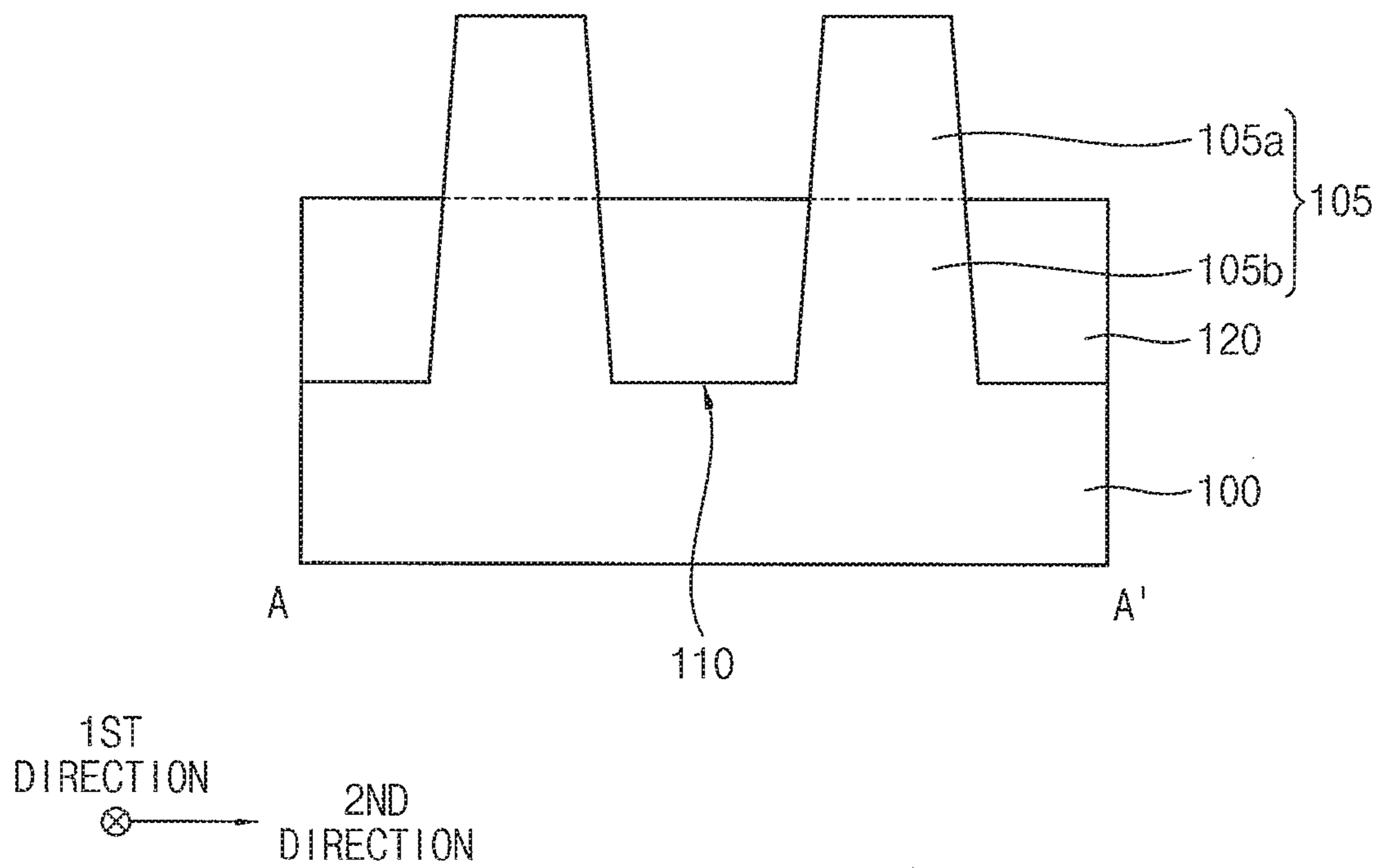


FIG. 6

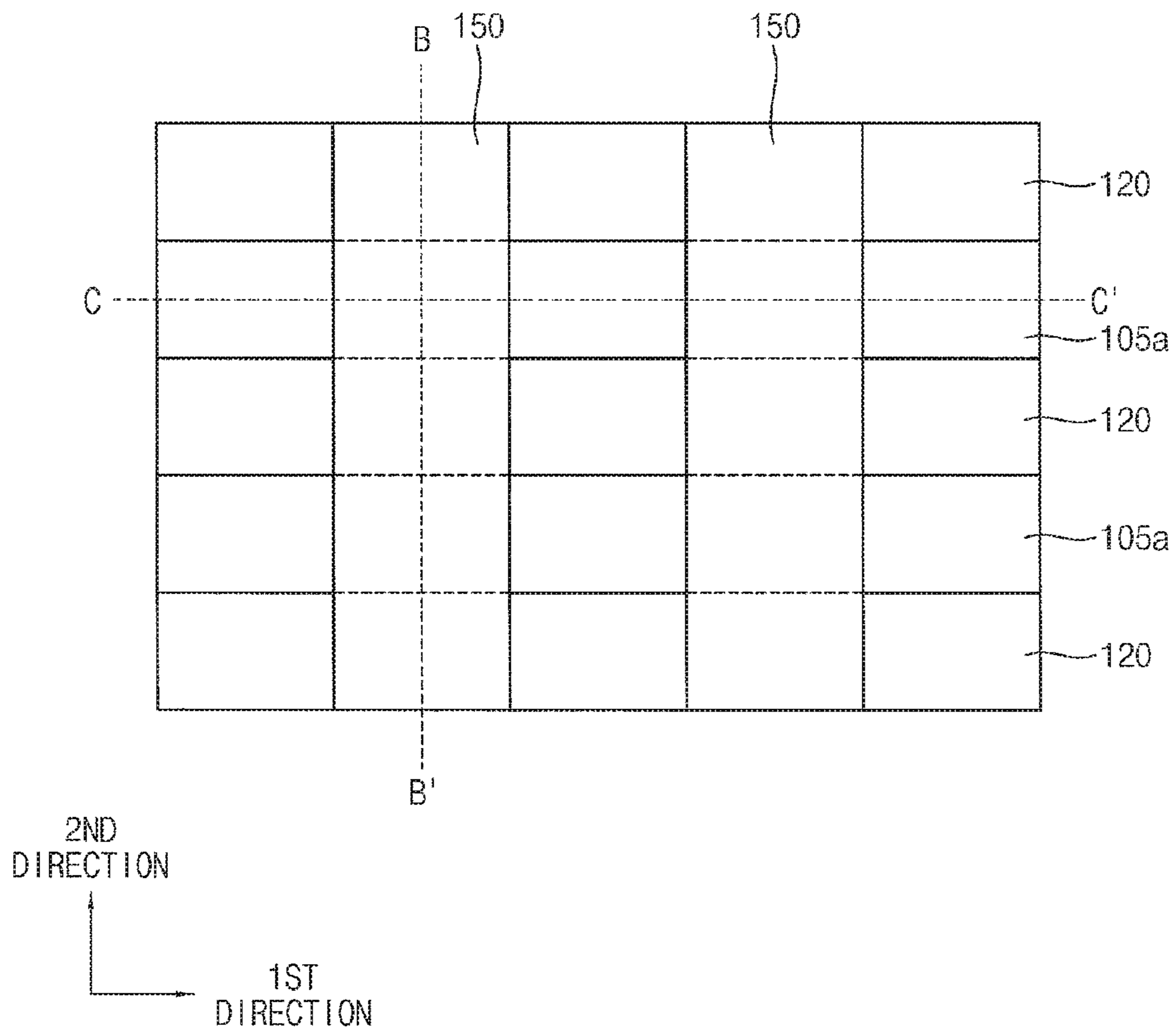




FIG. 7

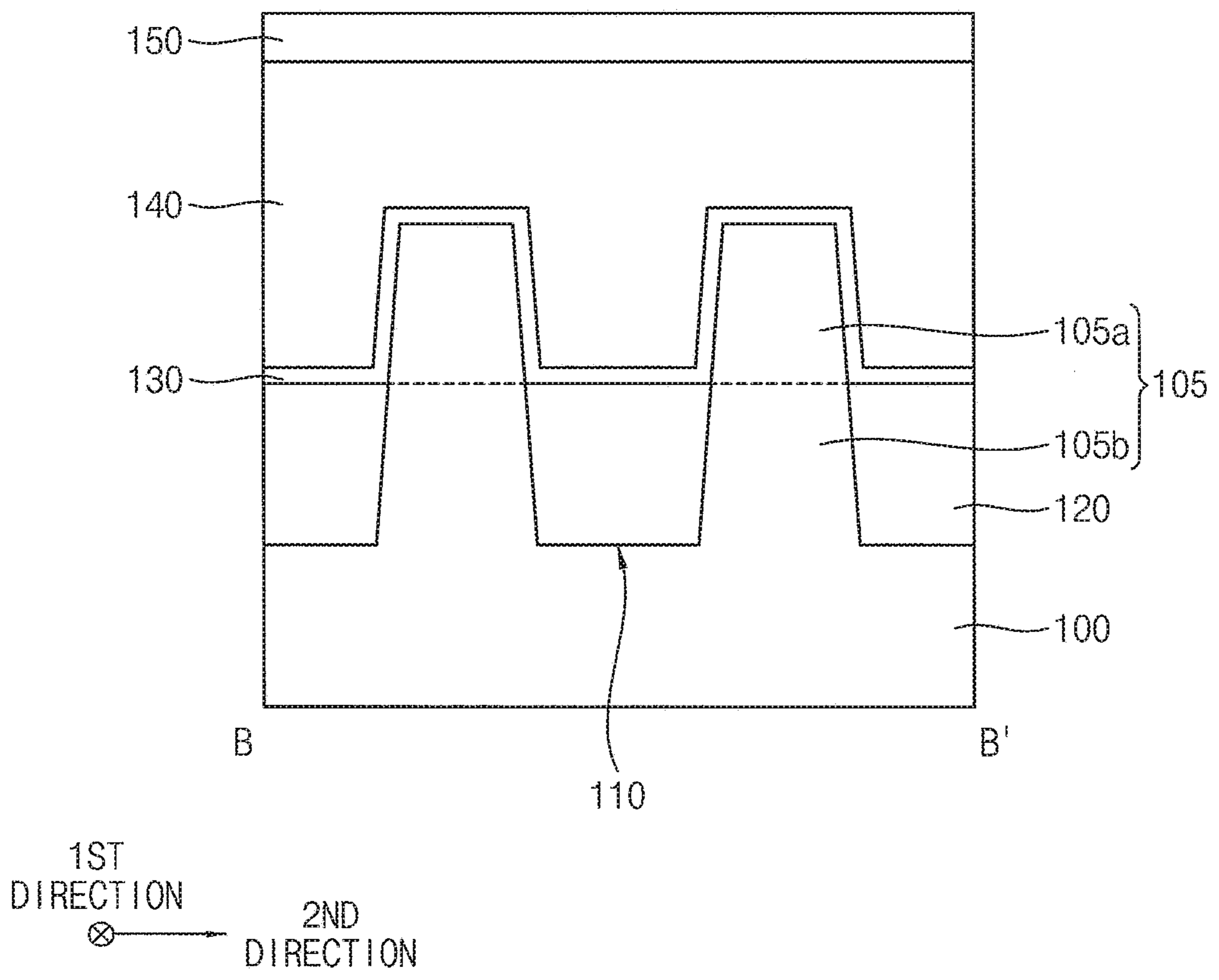




FIG. 8

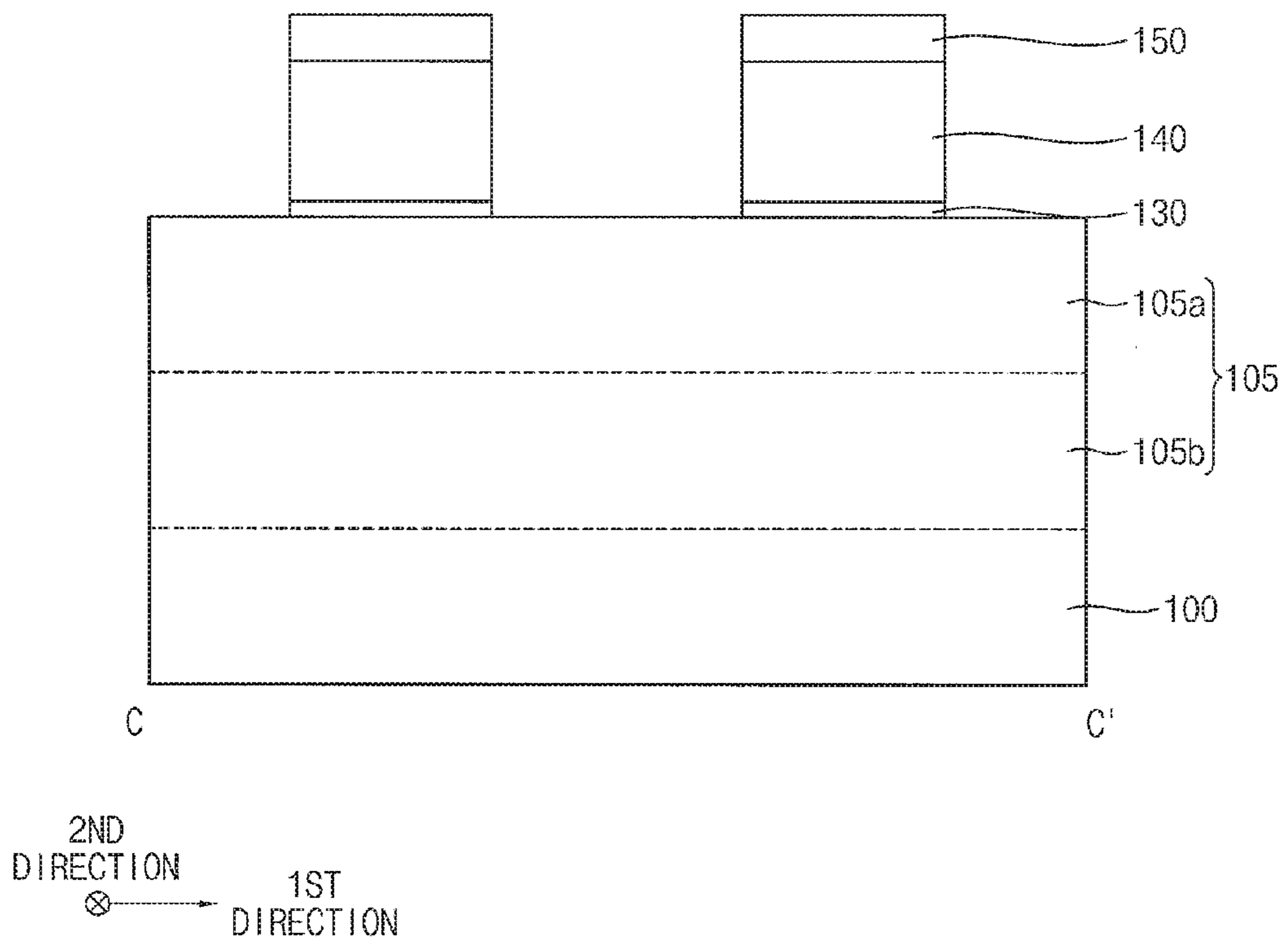


FIG. 9

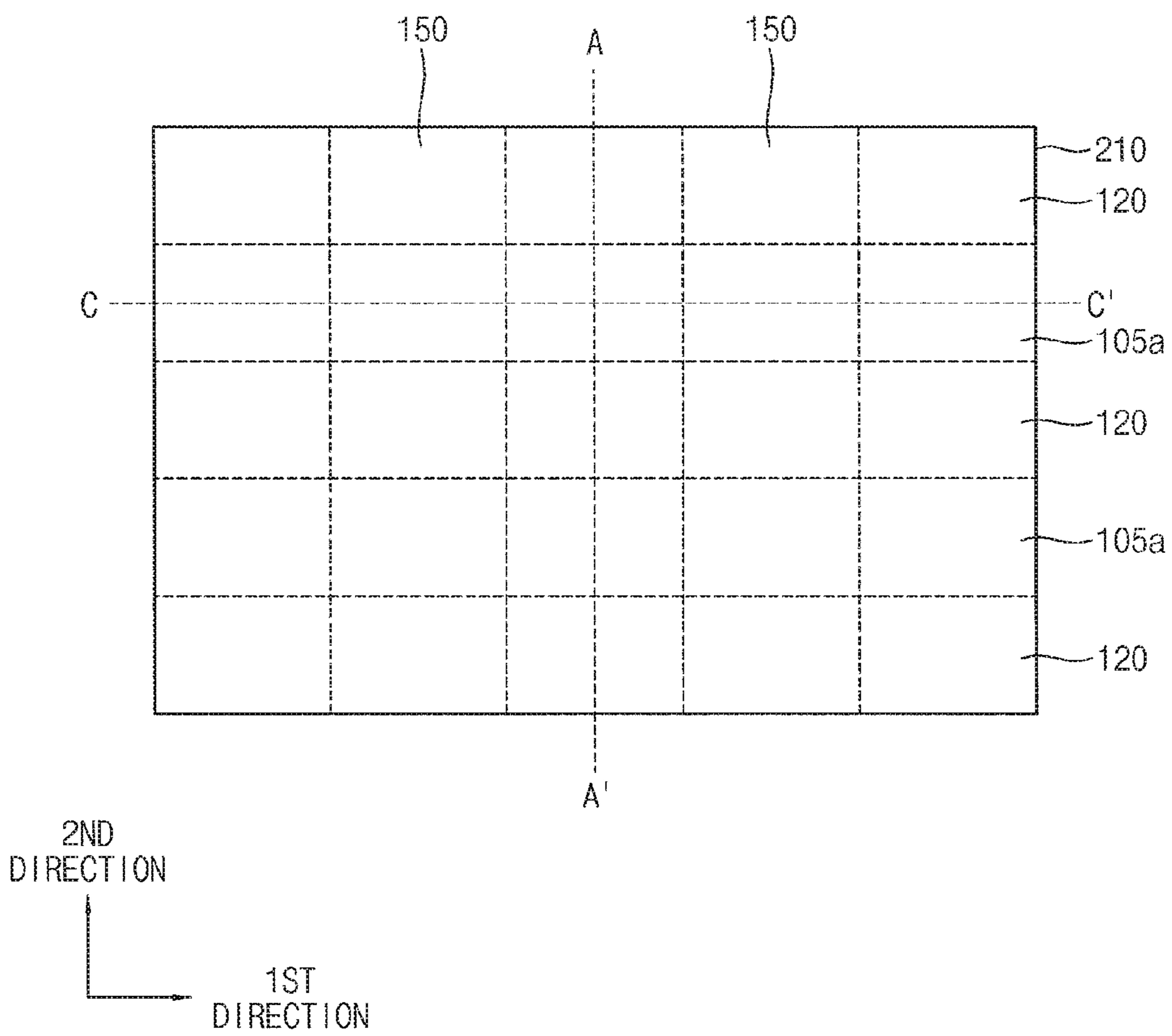


FIG. 10

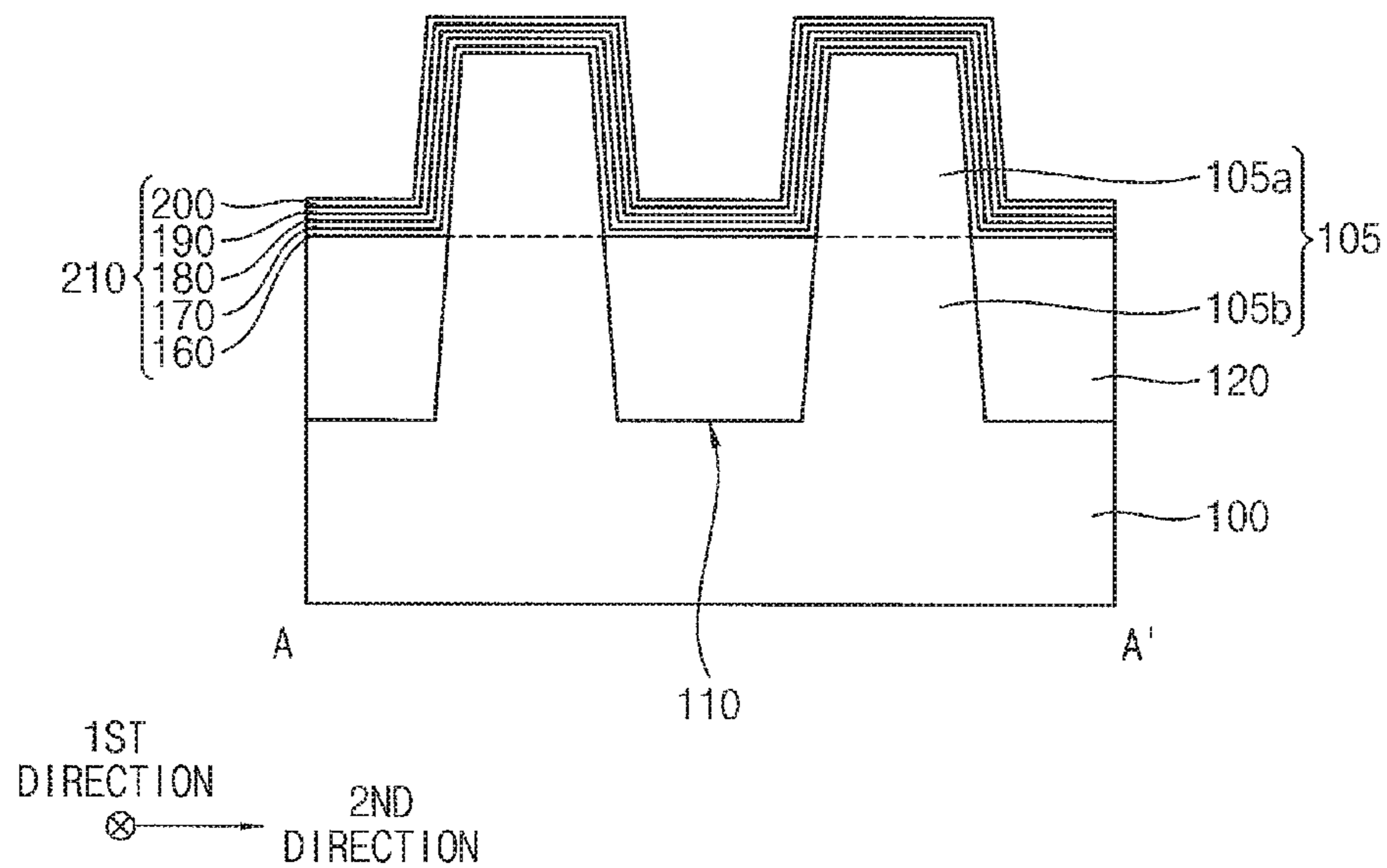


FIG. 11

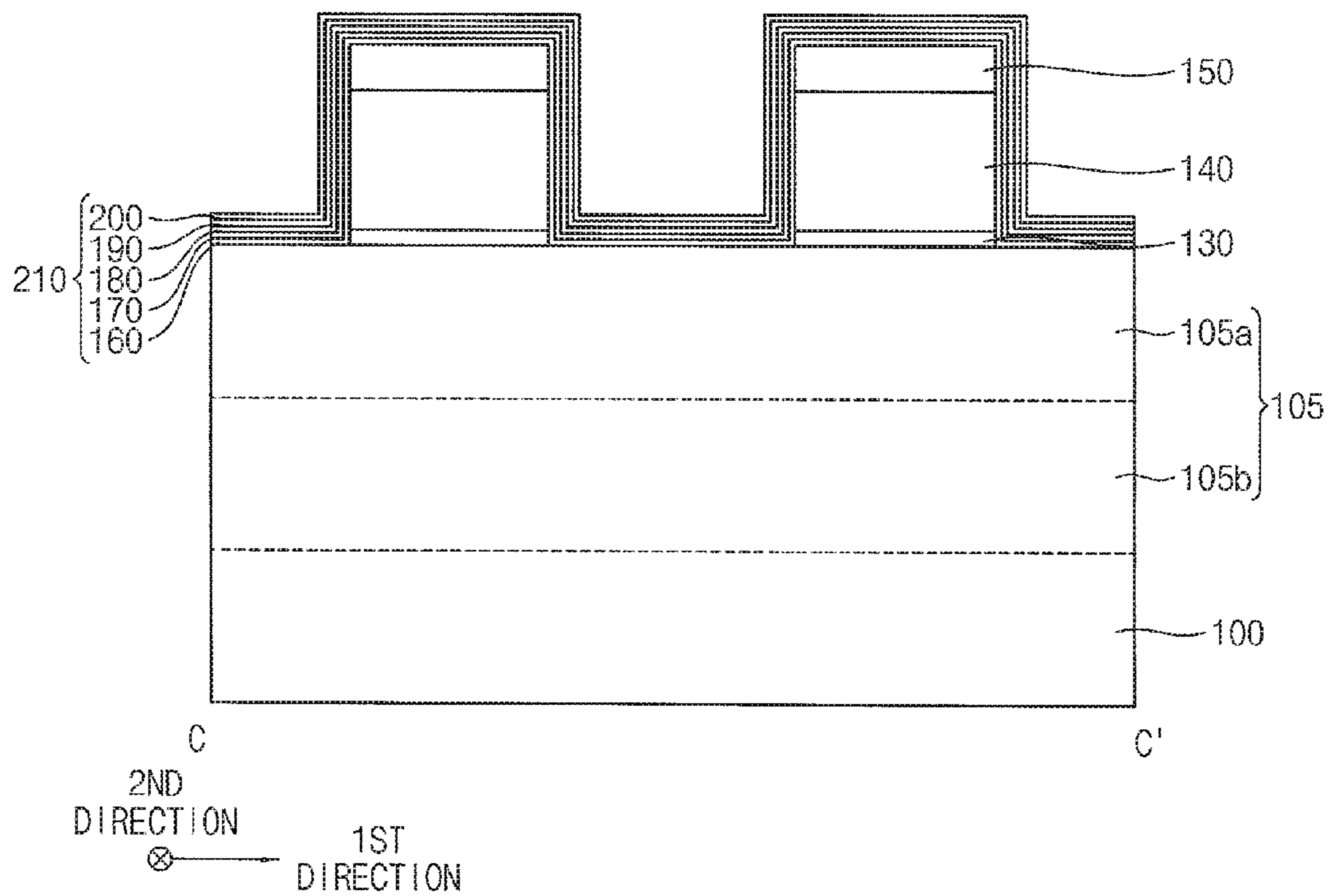


FIG. 12

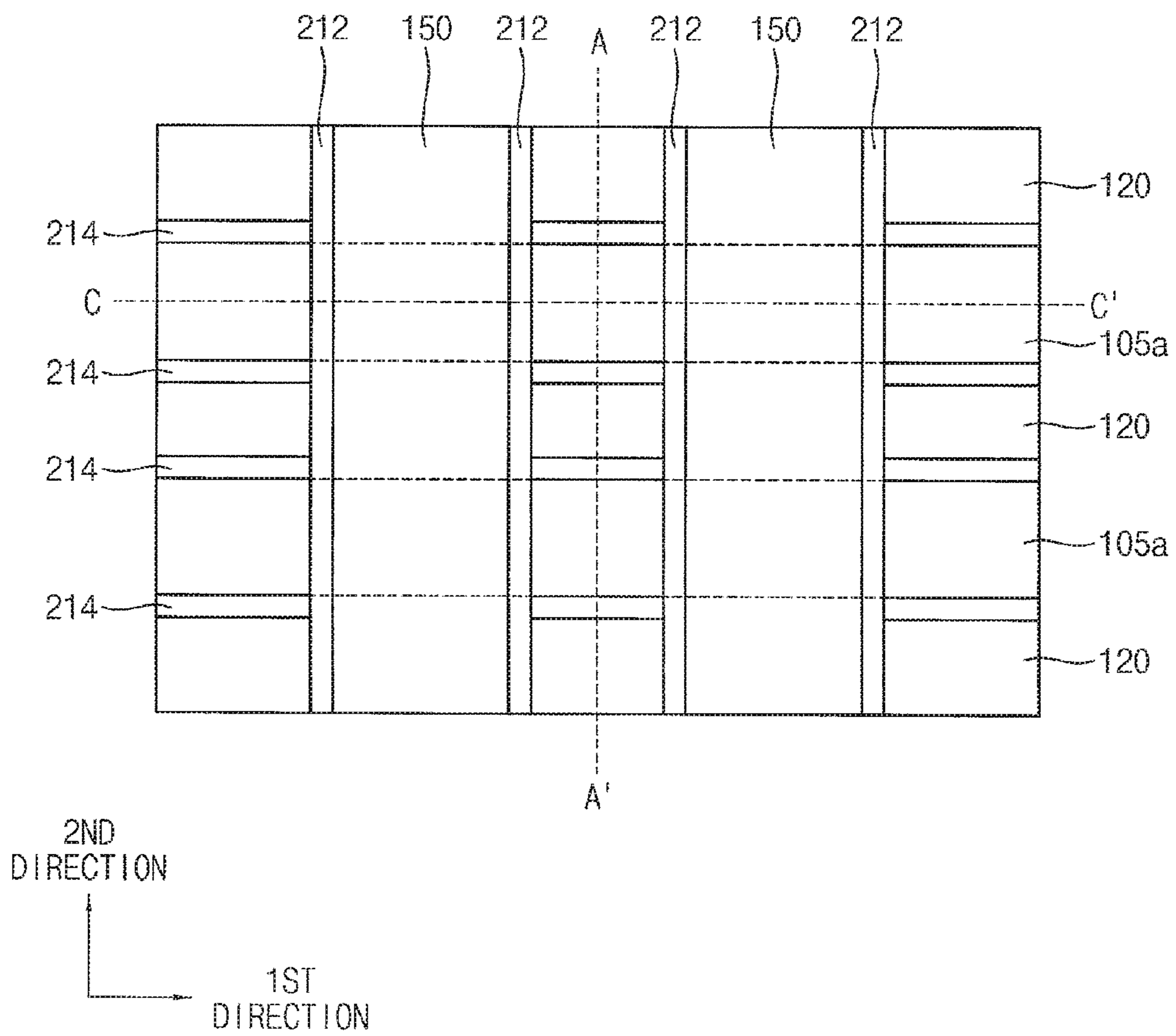


FIG. 13

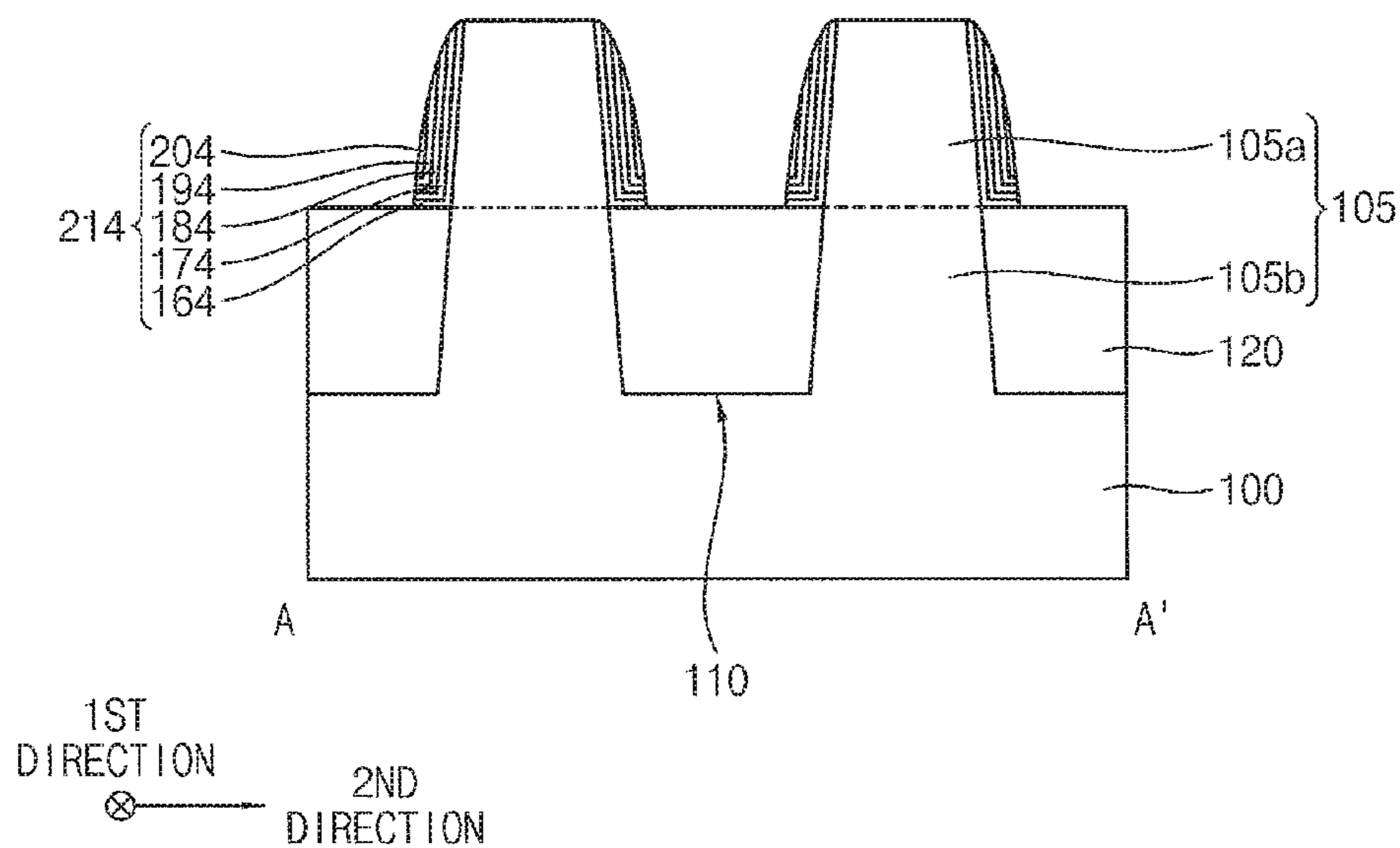


FIG. 14

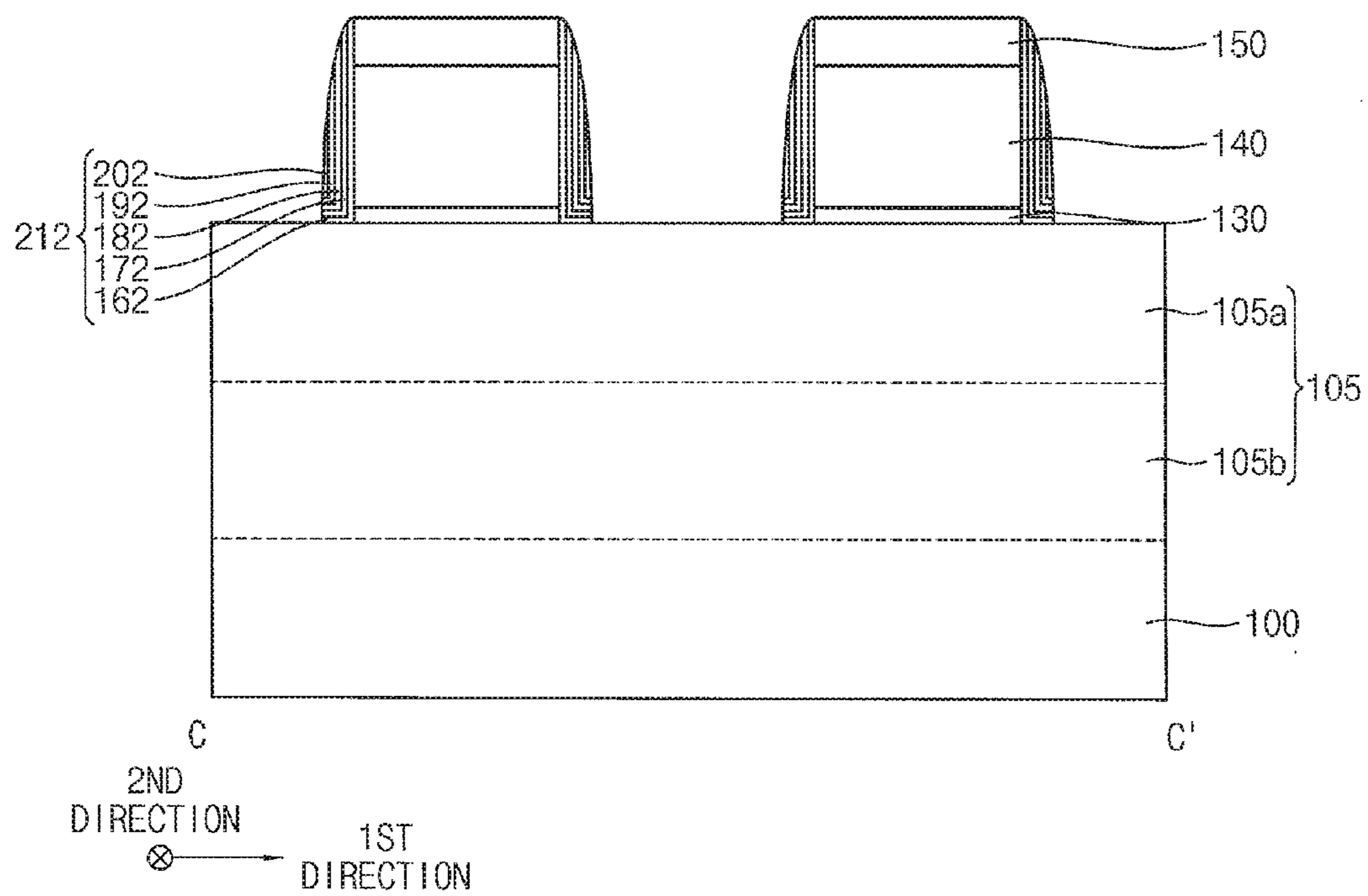


FIG. 15

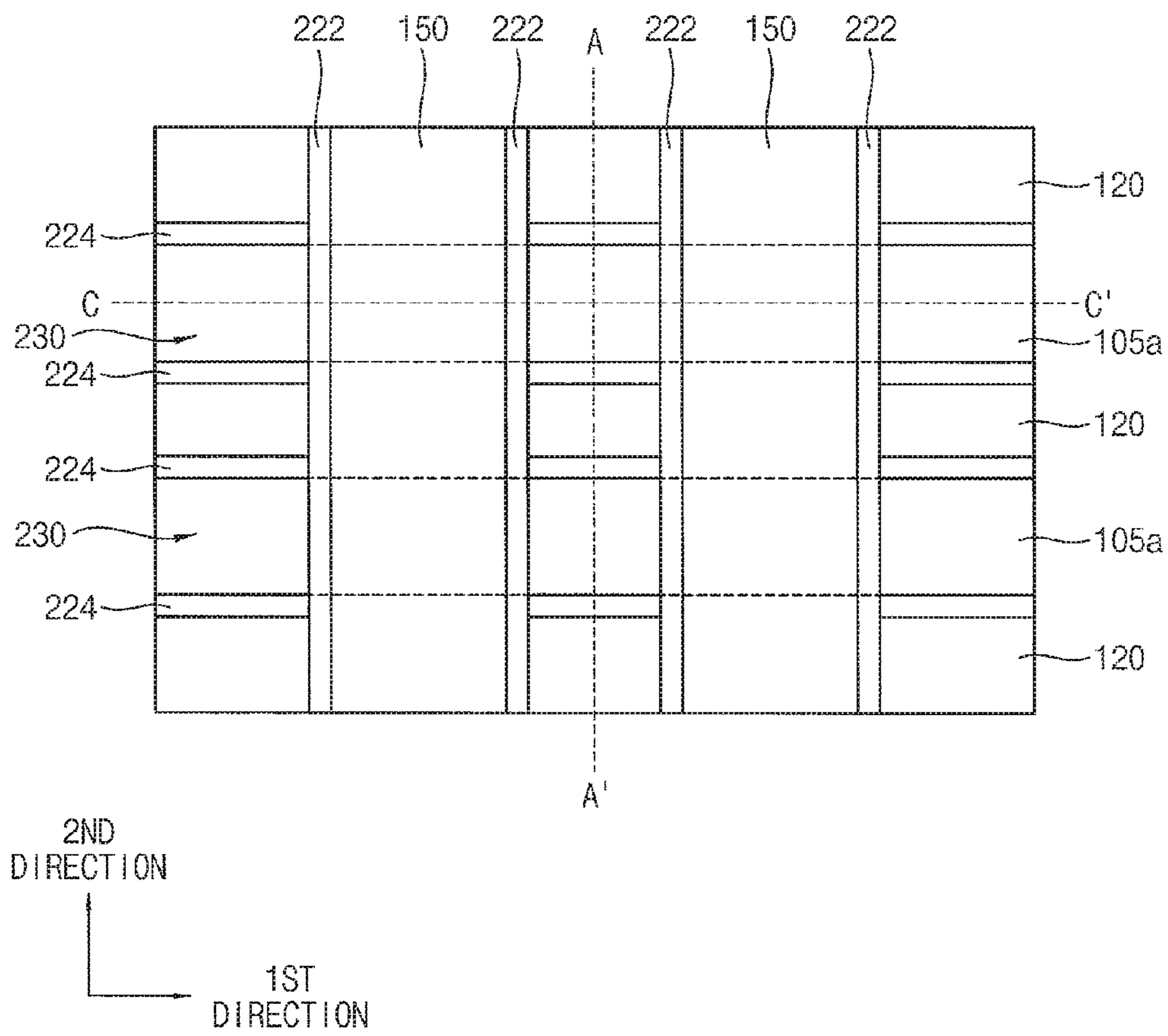


FIG. 16

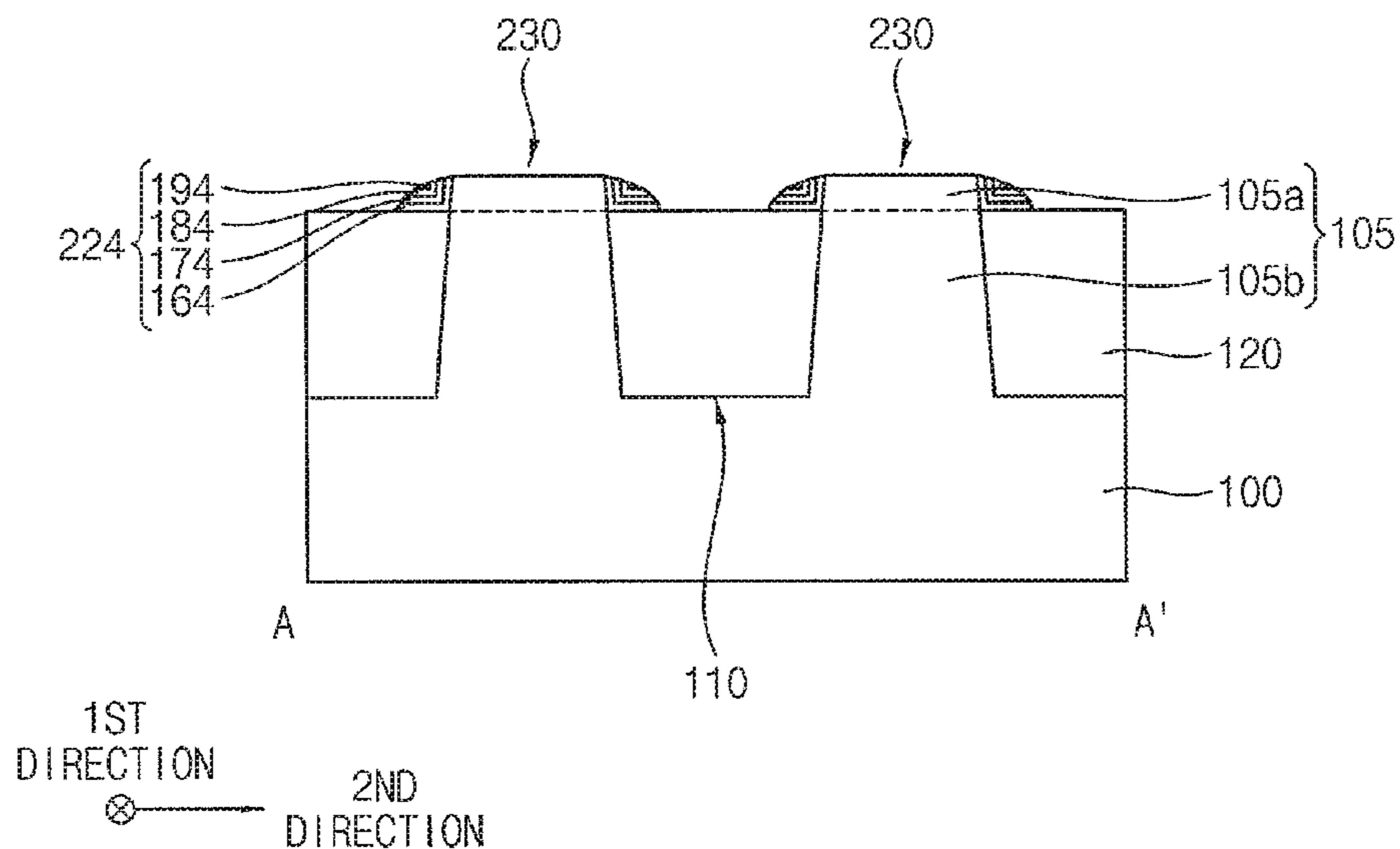


FIG. 17

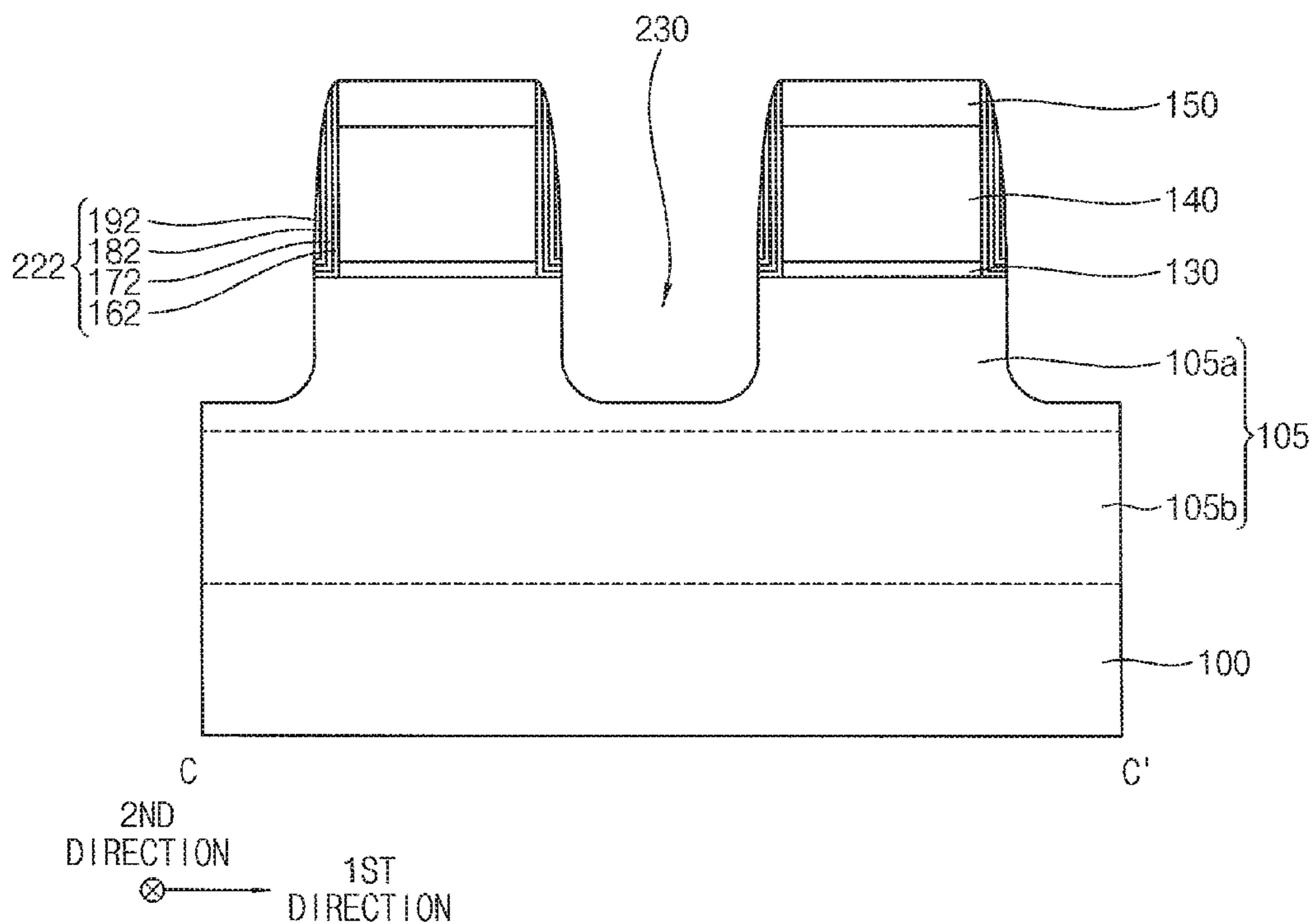




FIG. 18

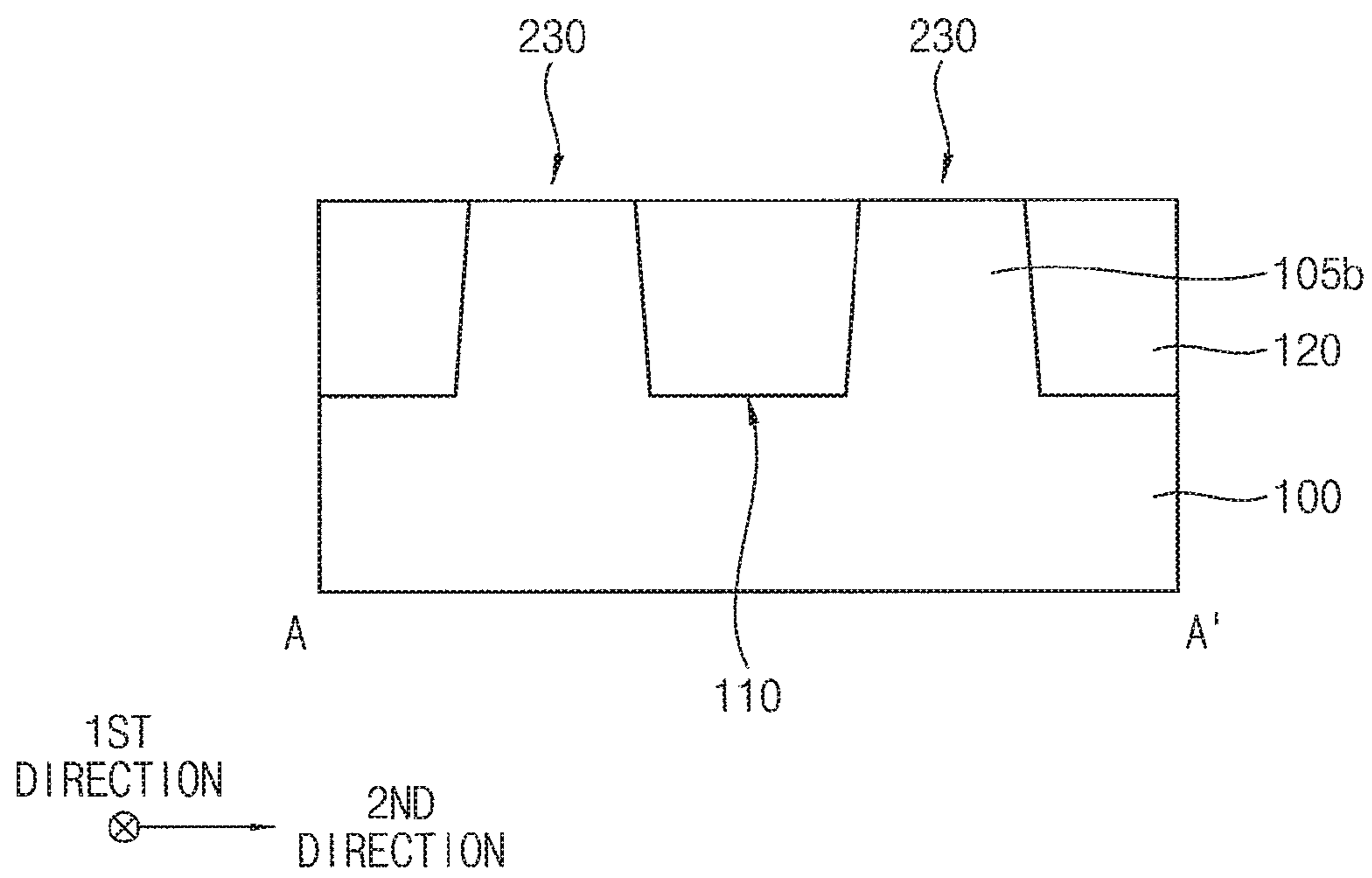


FIG. 19

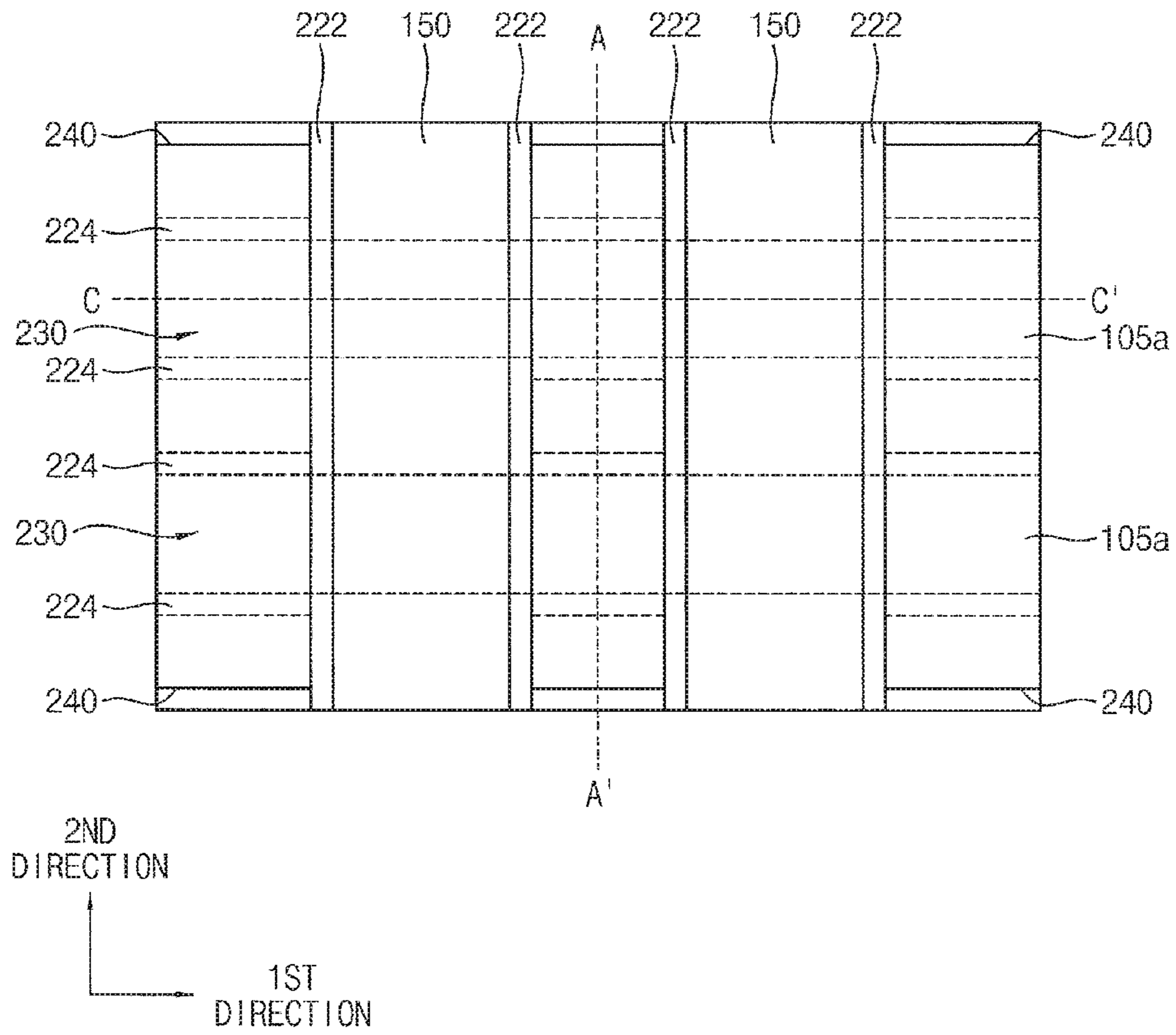


FIG. 20

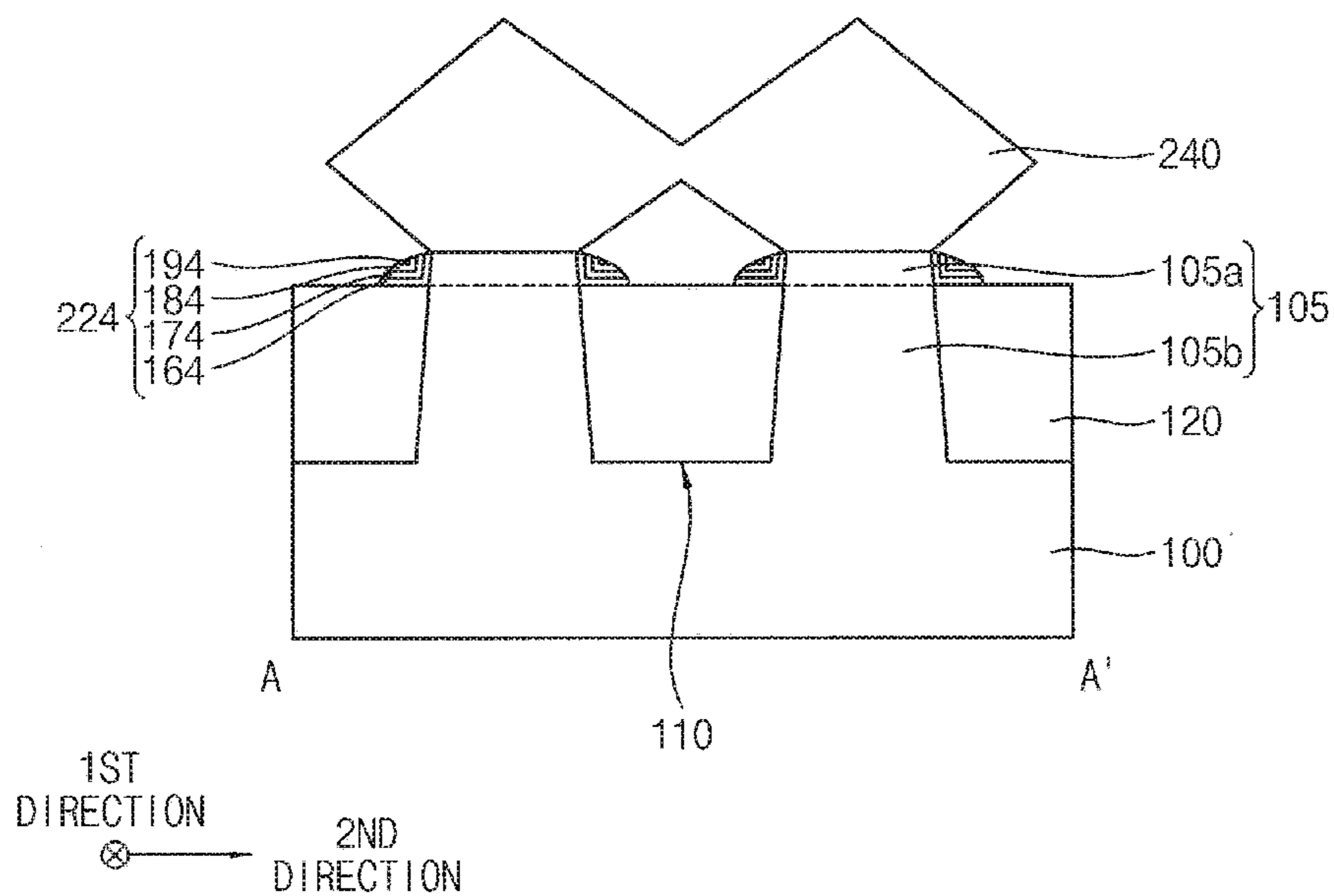


FIG. 21

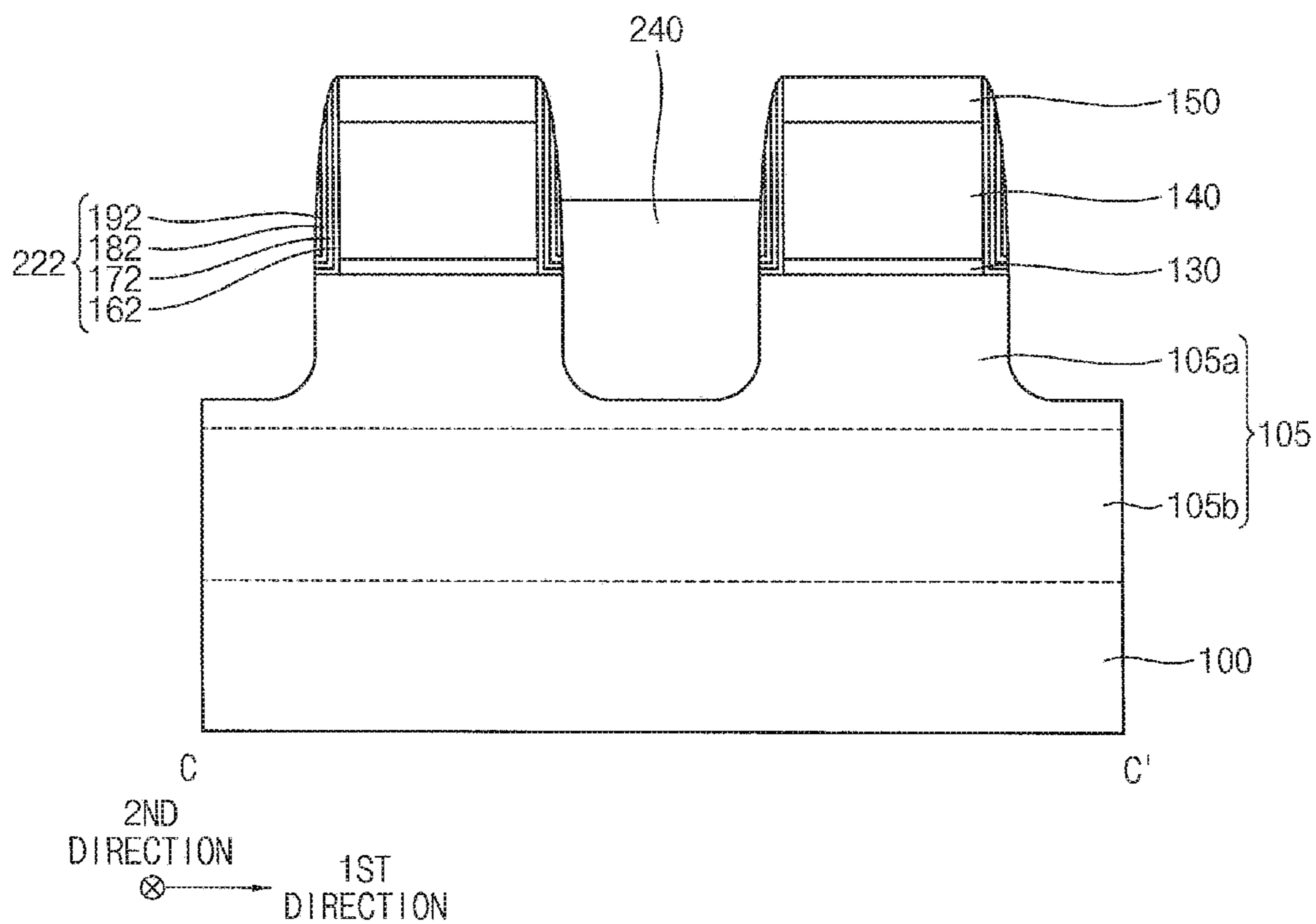


FIG. 22

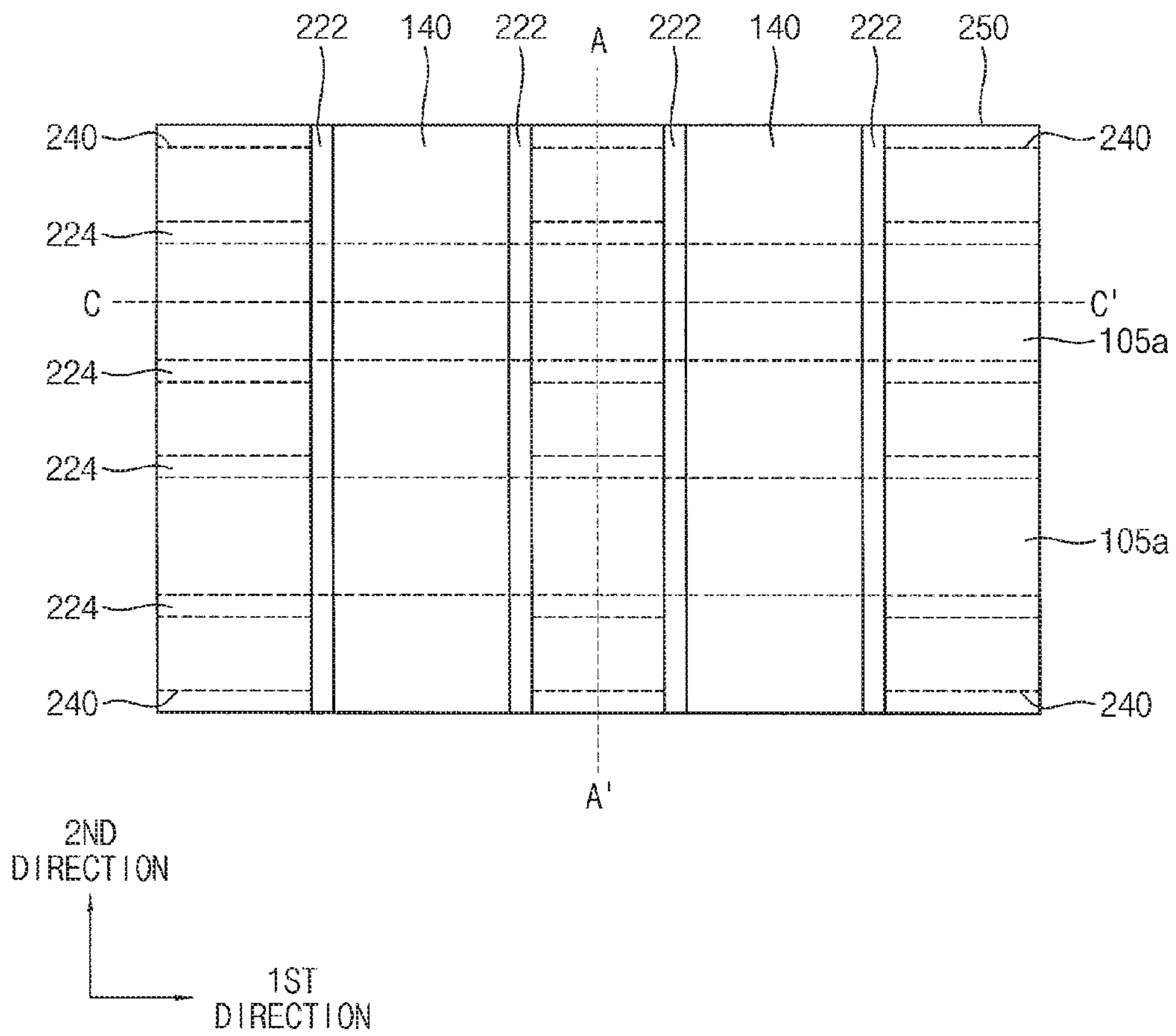


FIG. 23

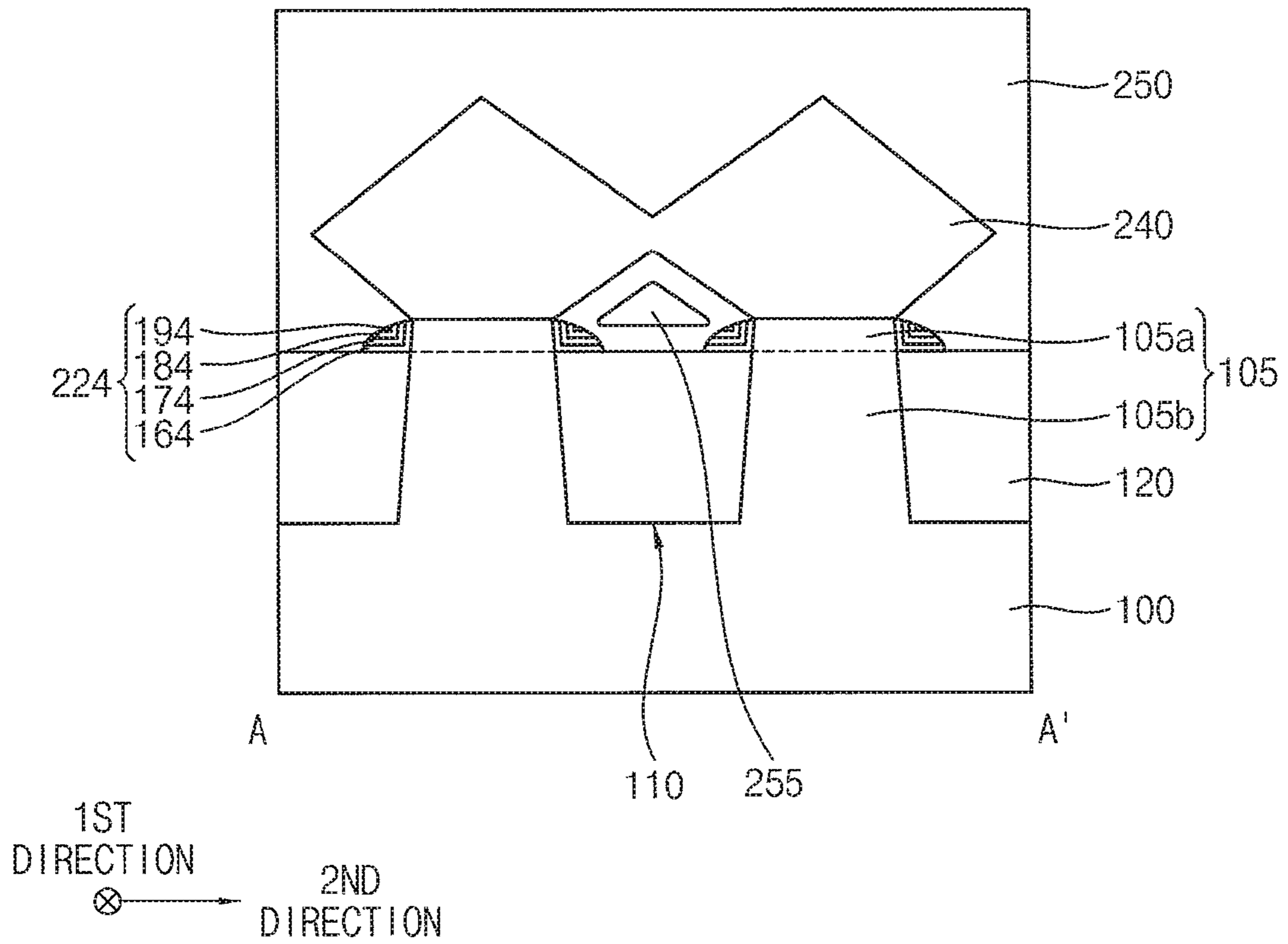


FIG. 24

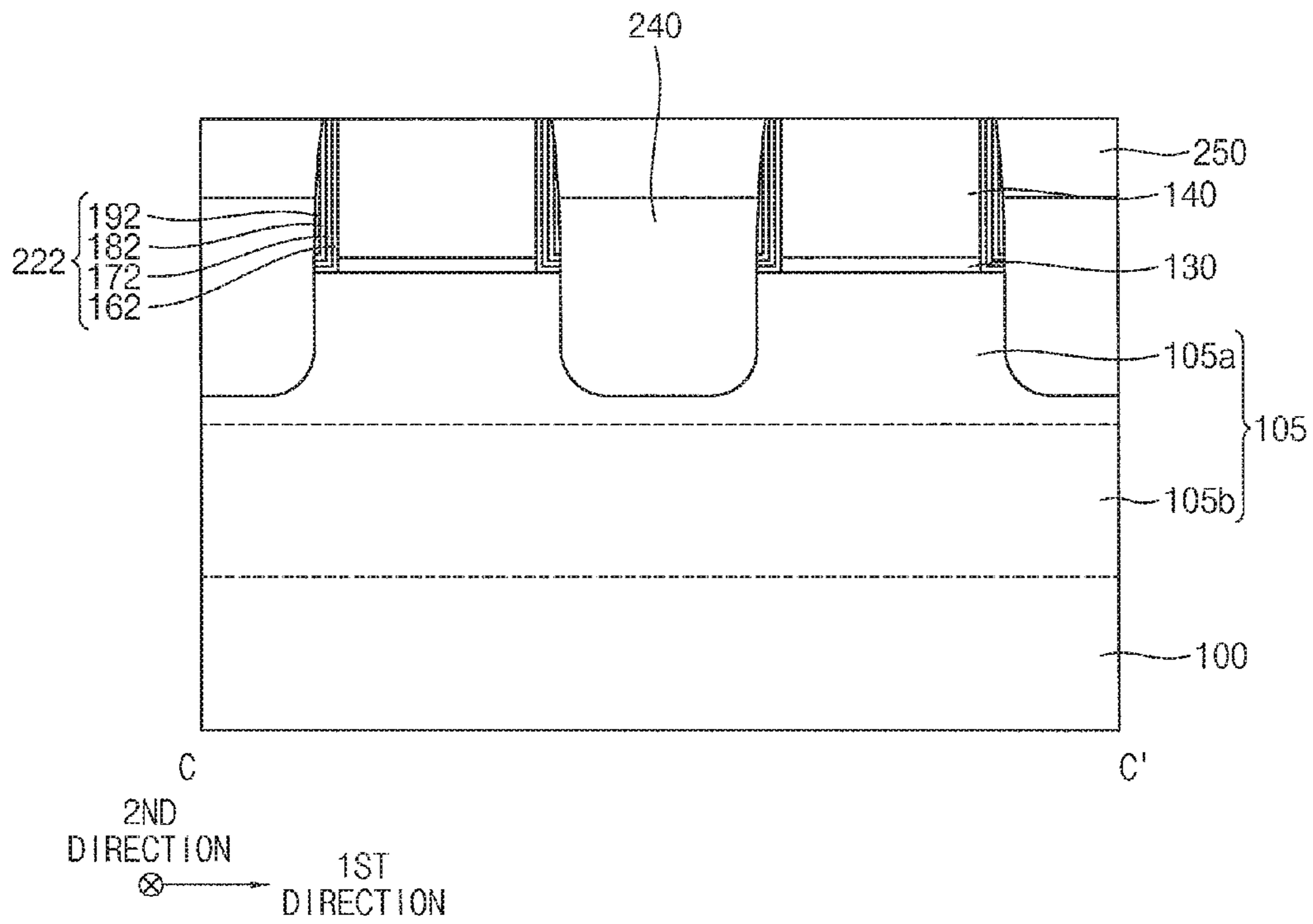


FIG. 25

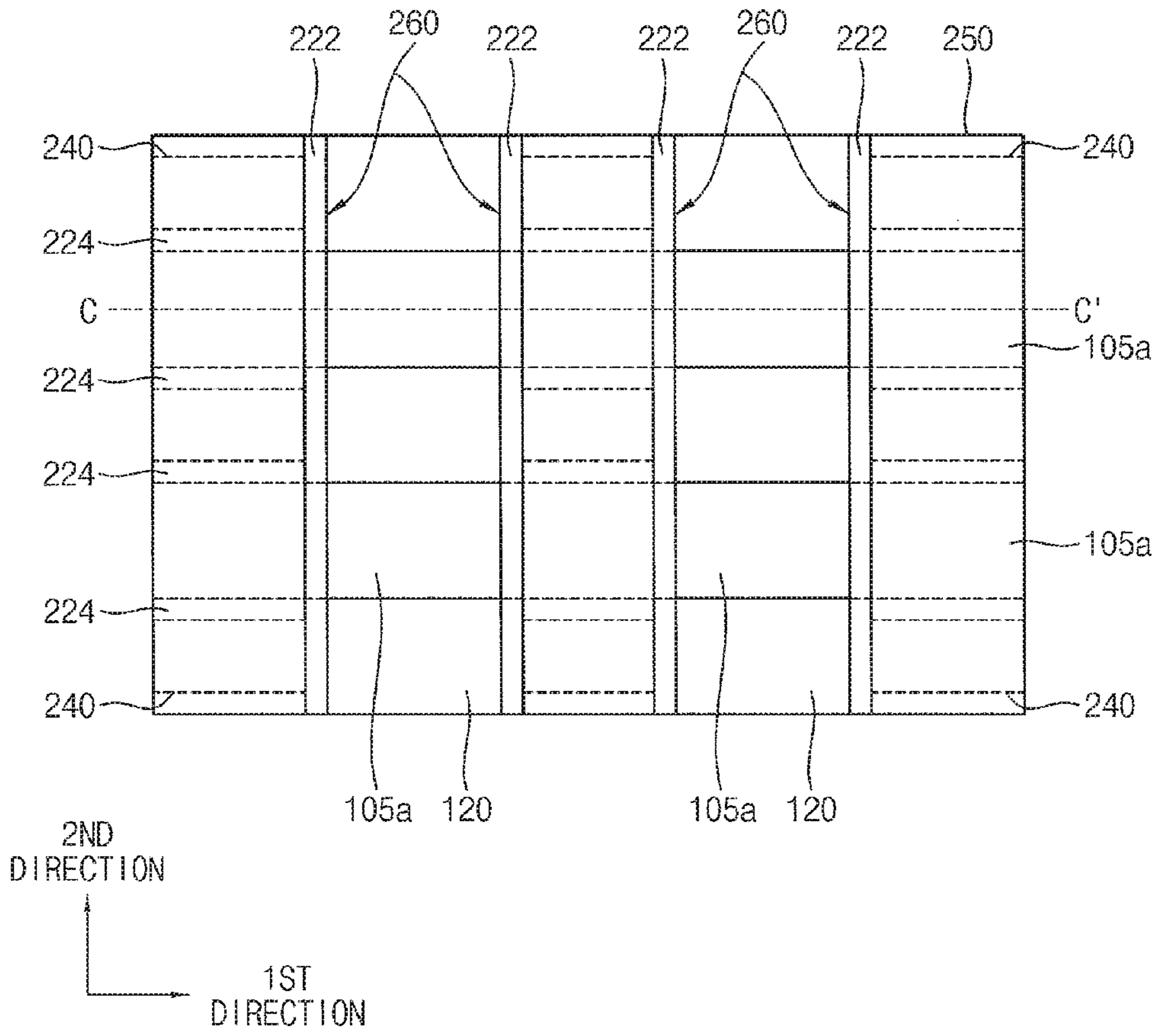




FIG. 26

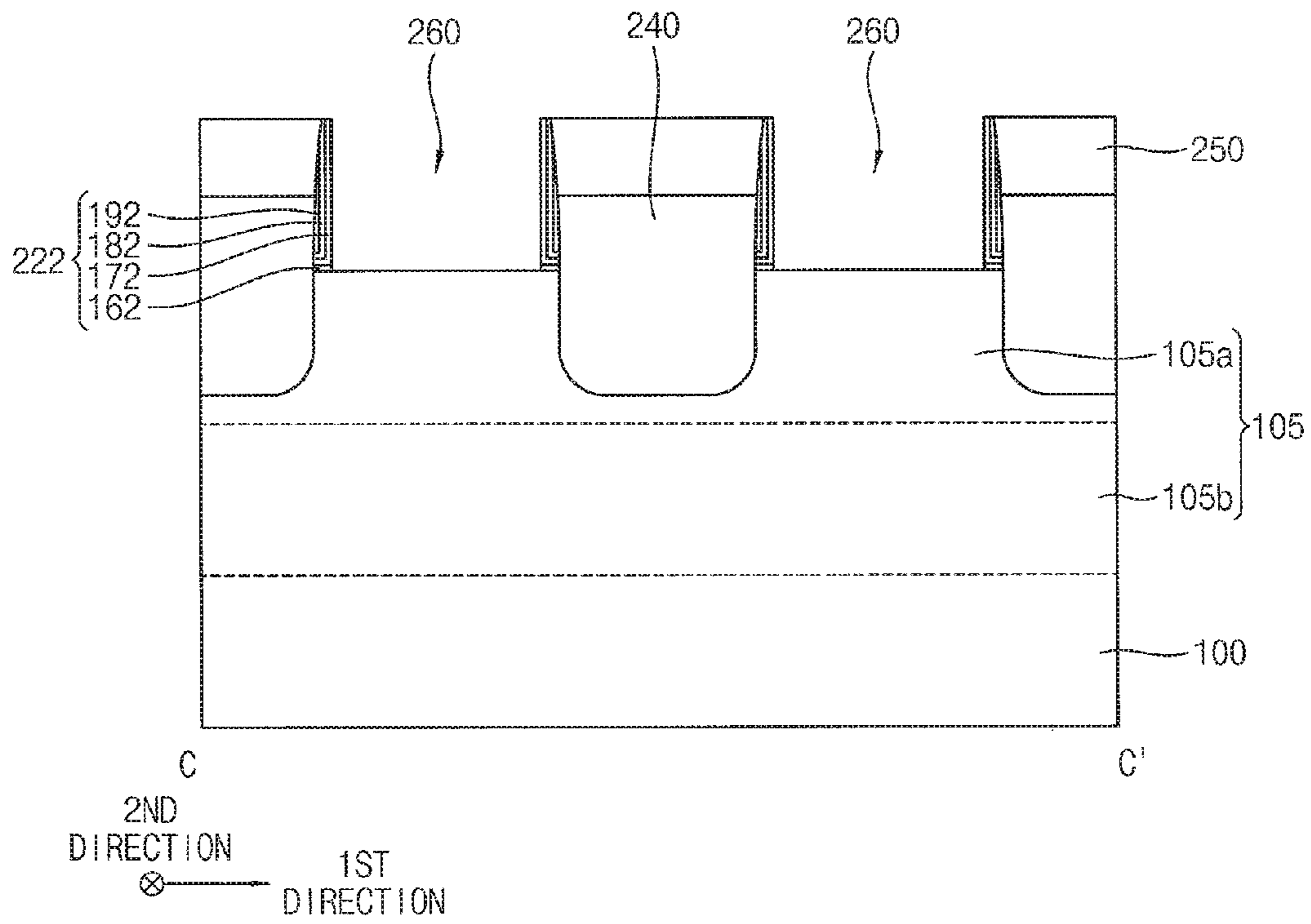


FIG. 27

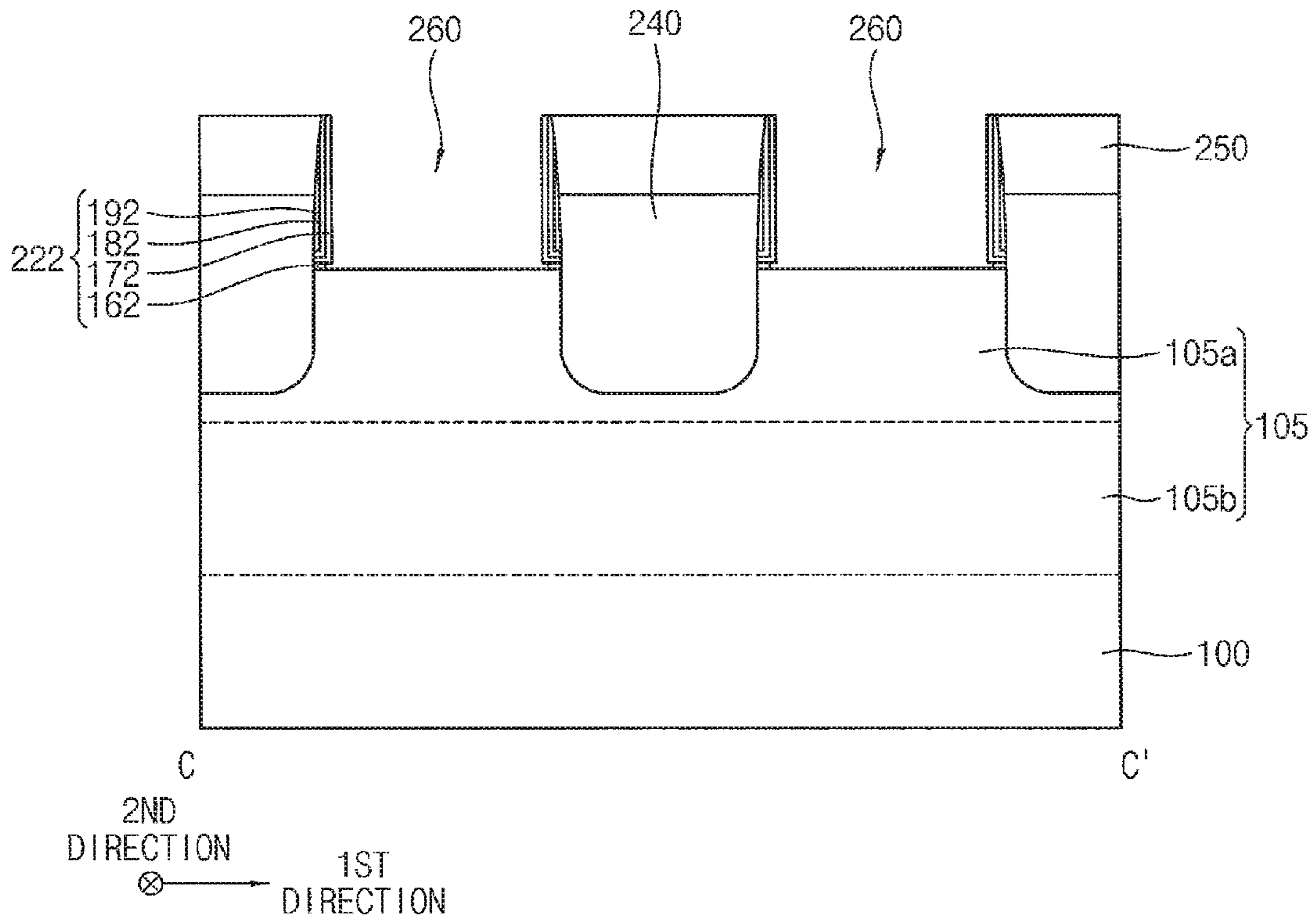


FIG. 28

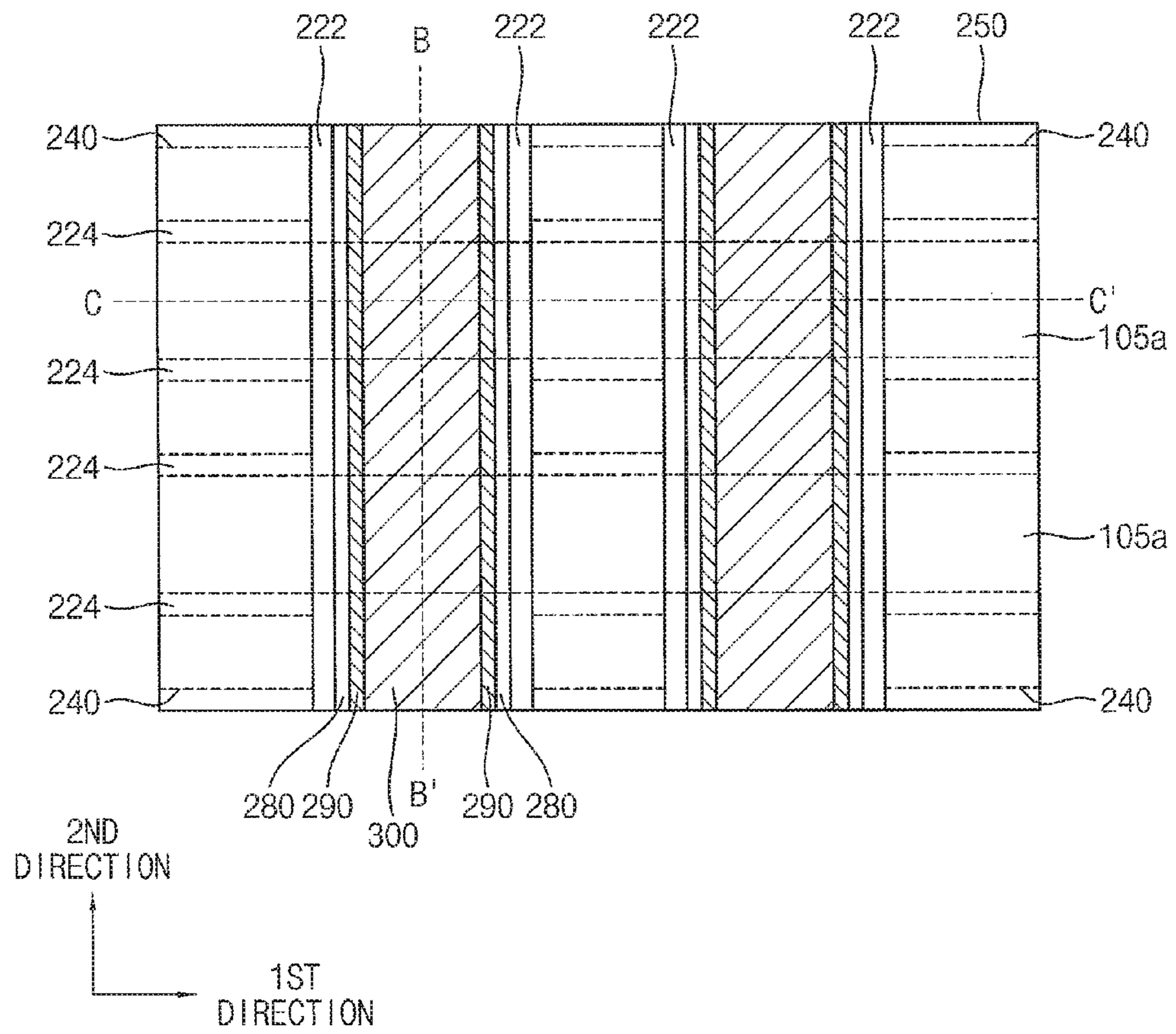


FIG. 29

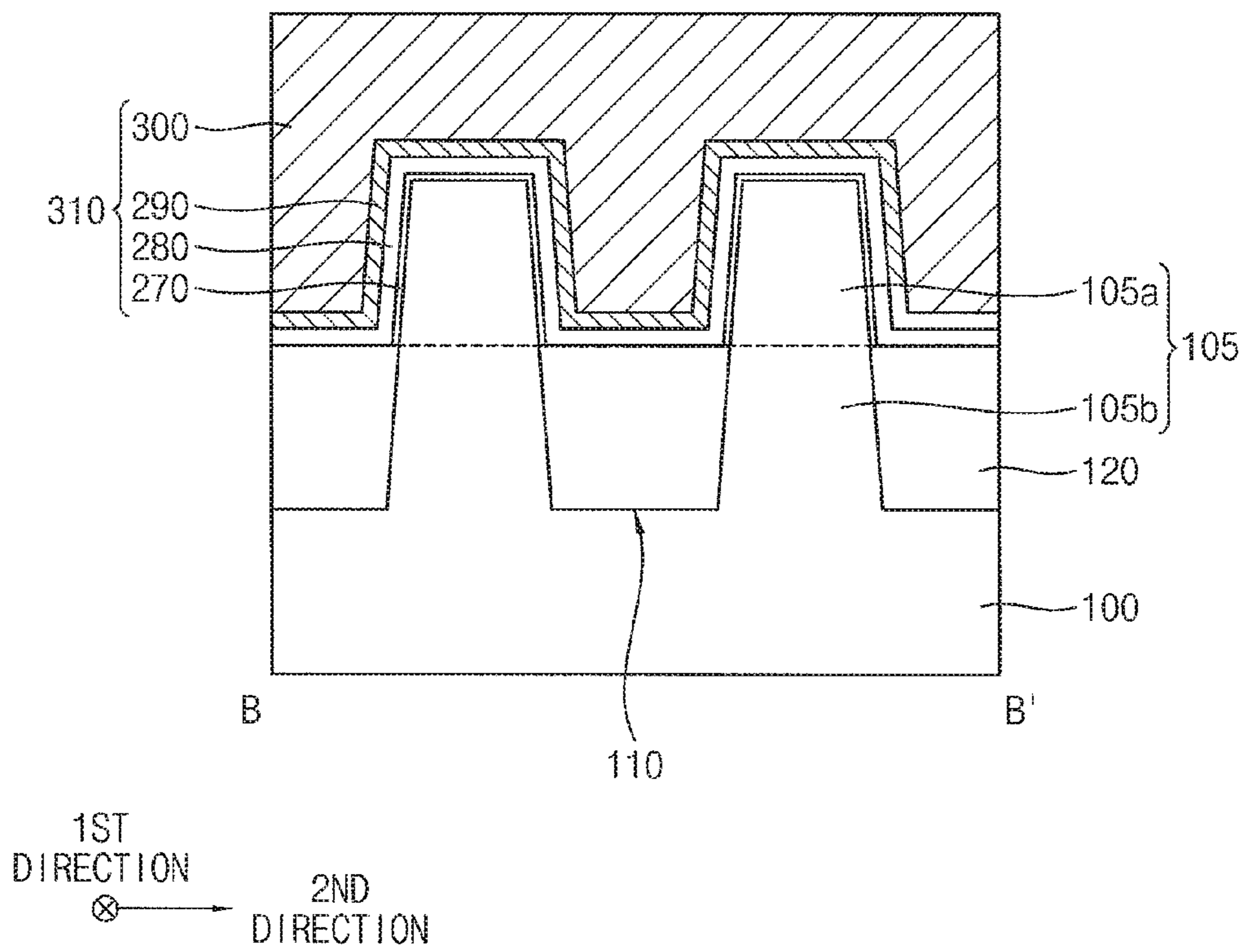


FIG. 30

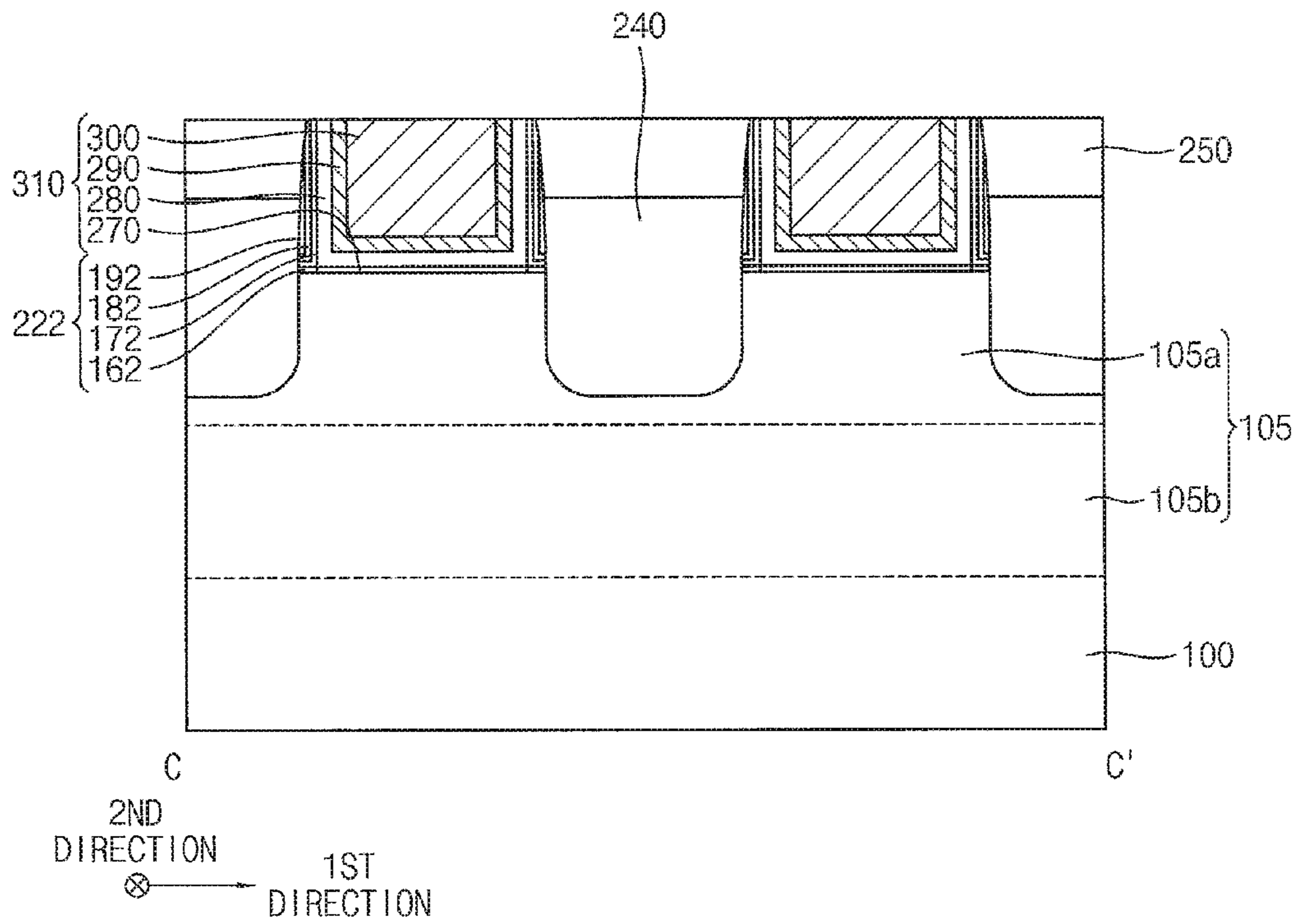


FIG. 31

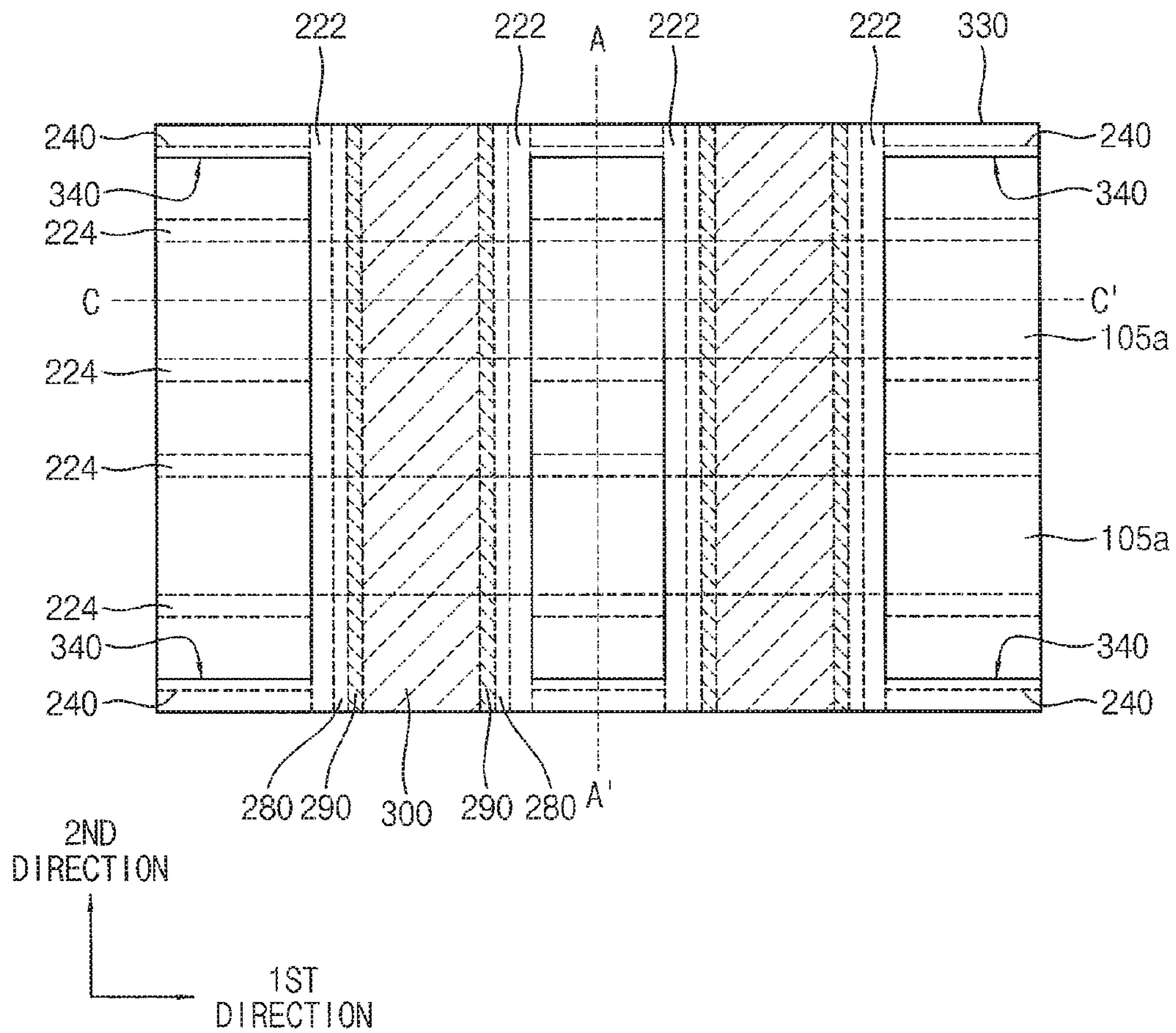




FIG. 32

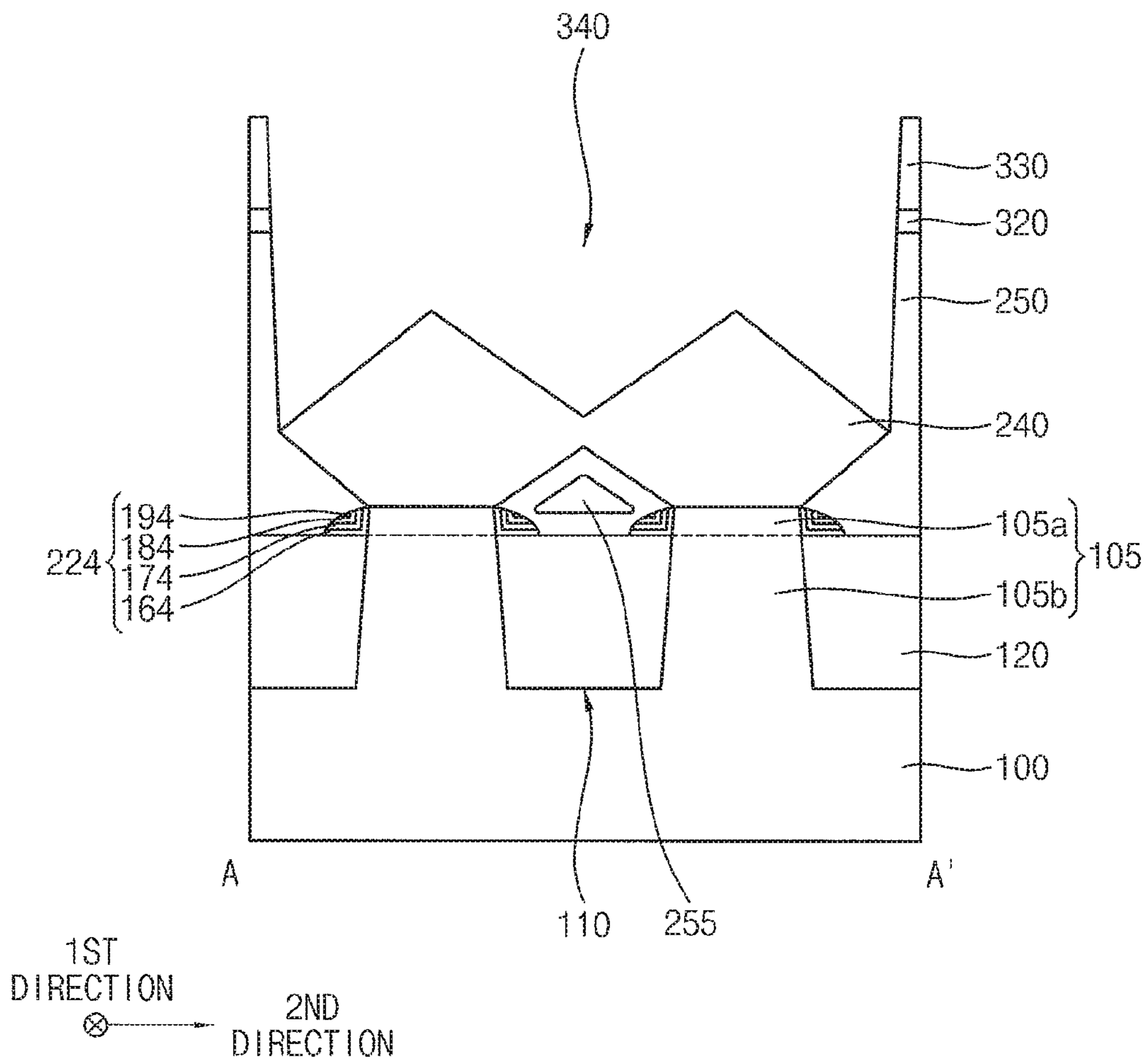




FIG. 33

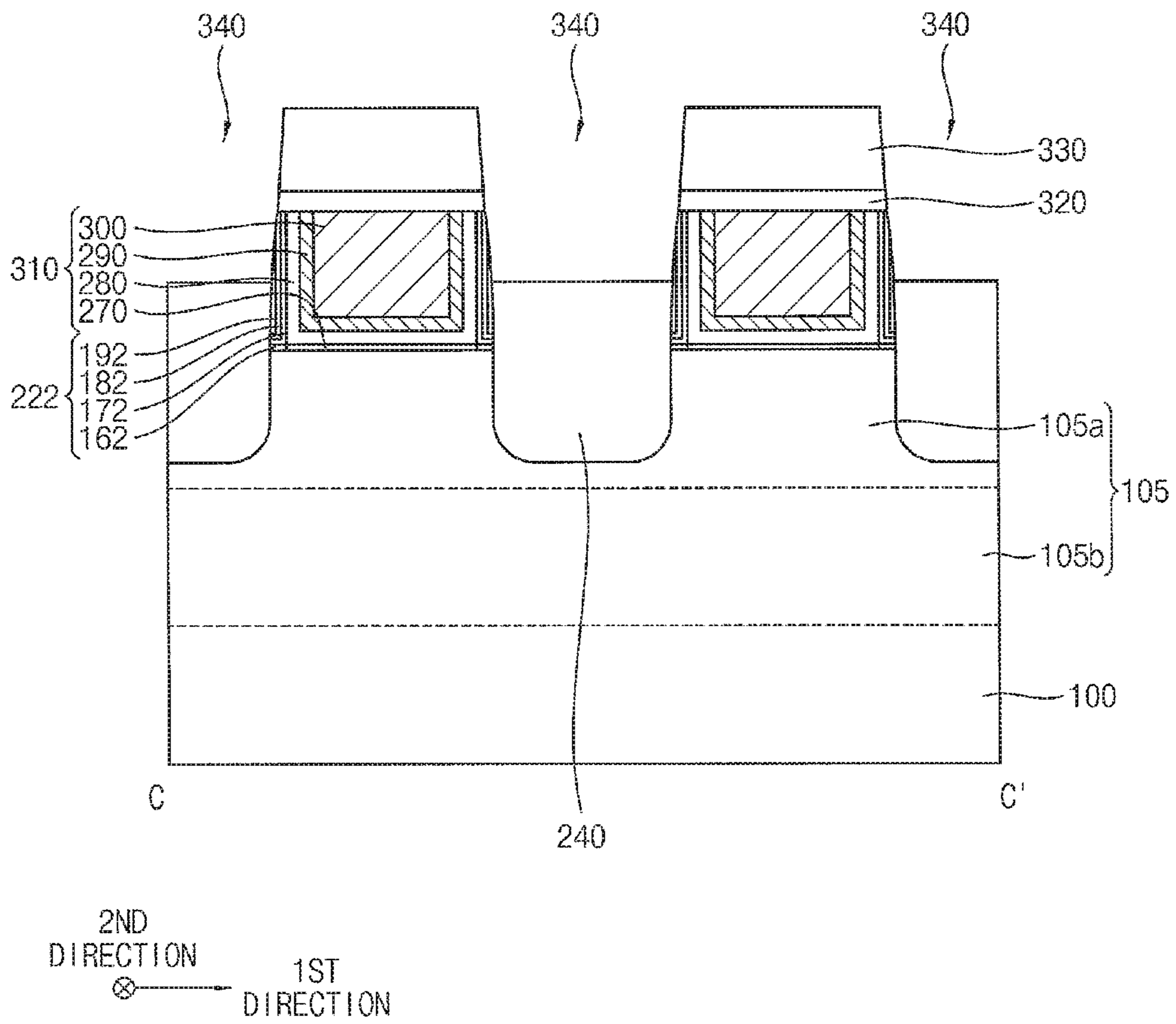


FIG. 34

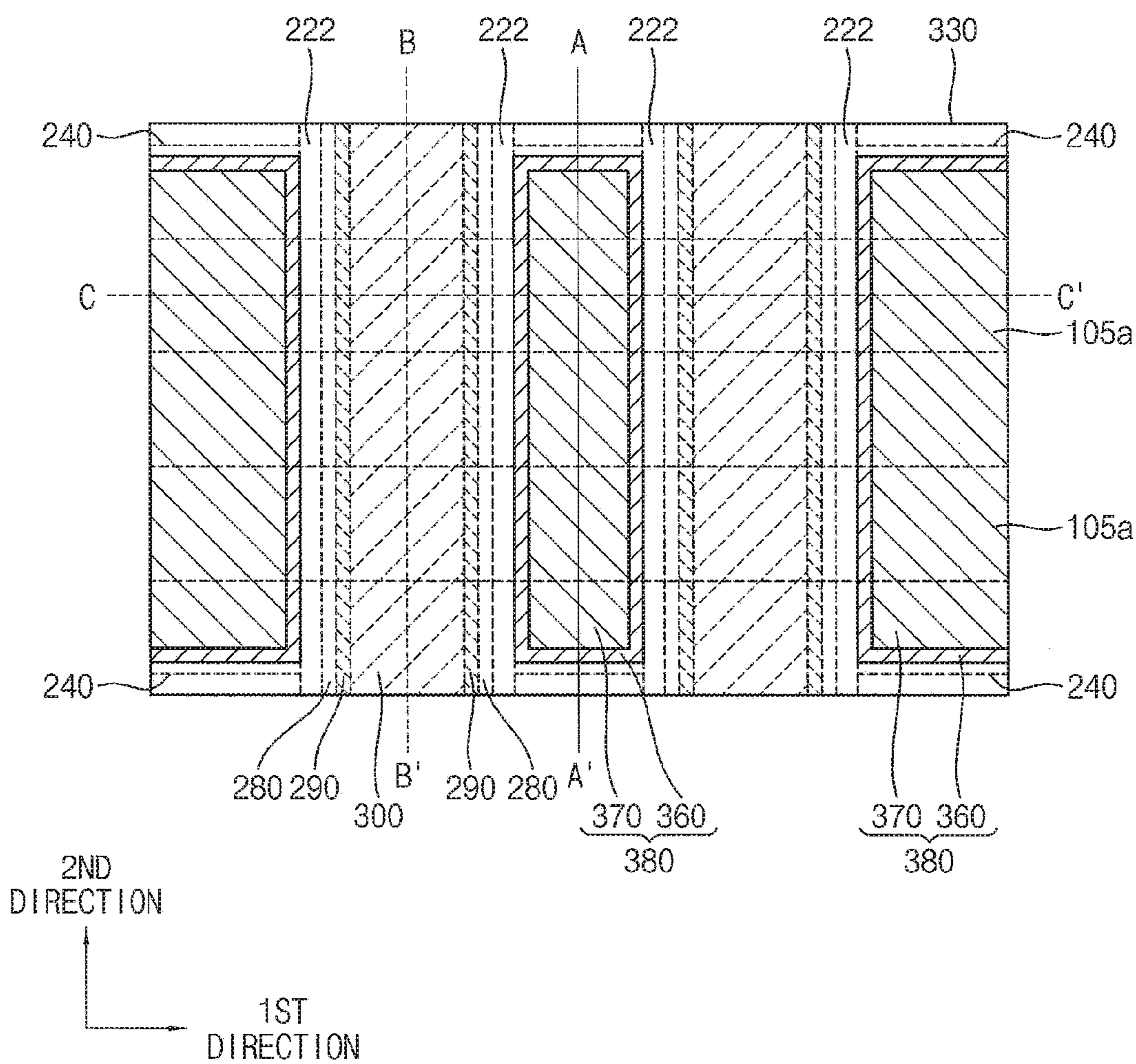


FIG. 35

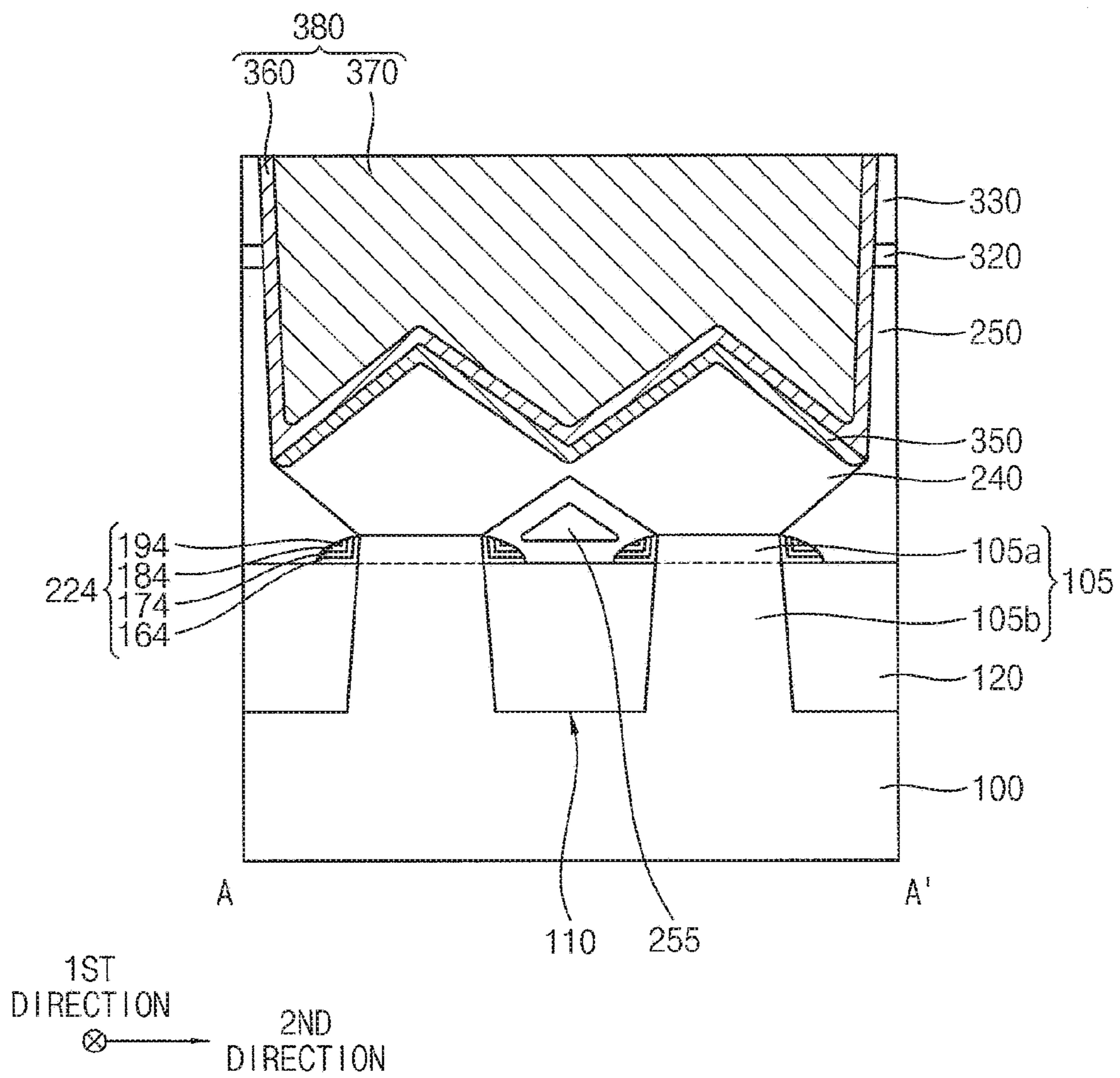


FIG. 36

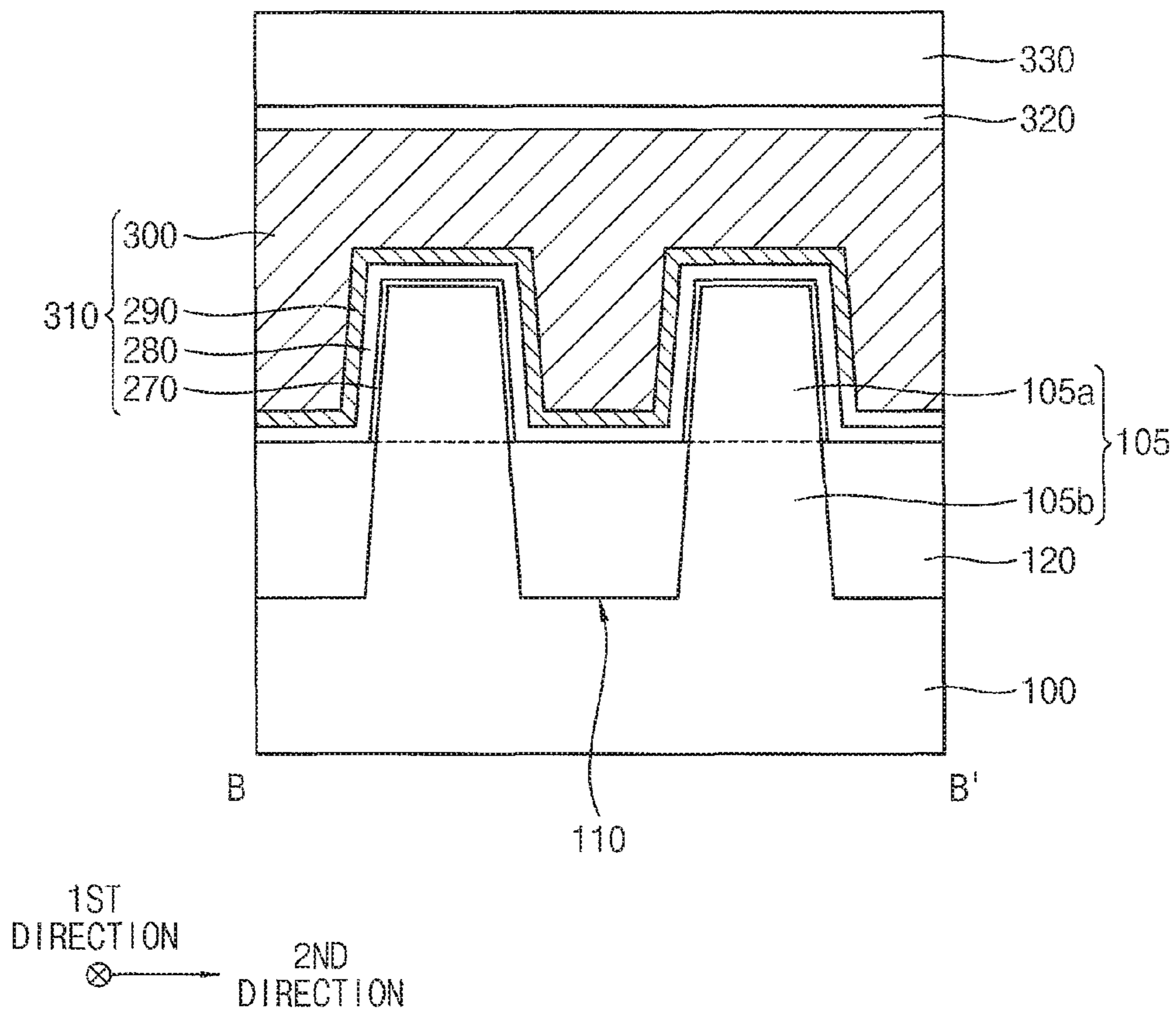




FIG. 37

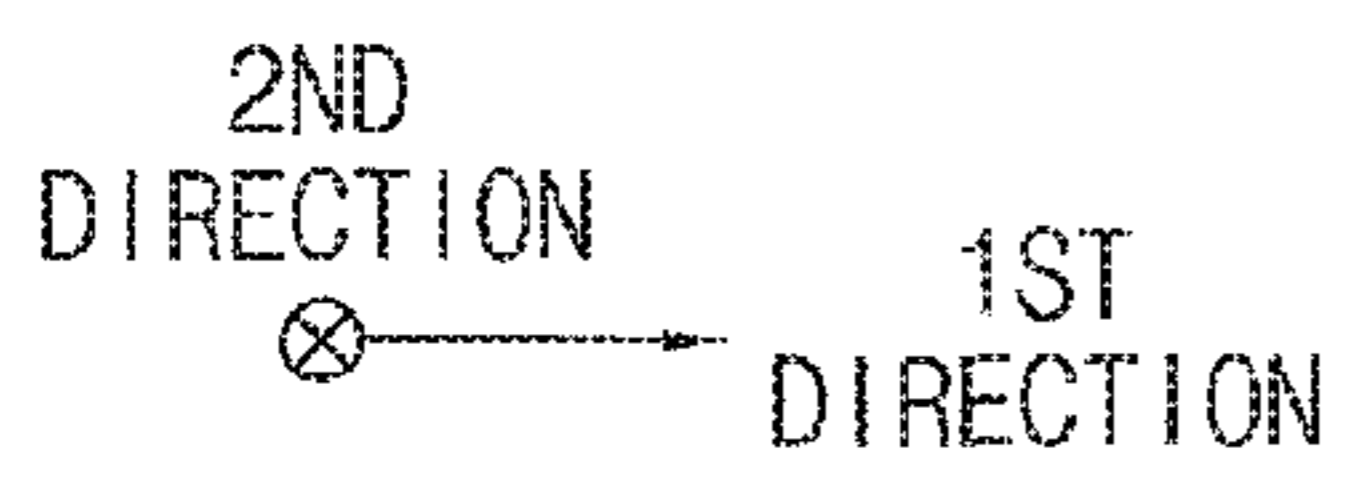
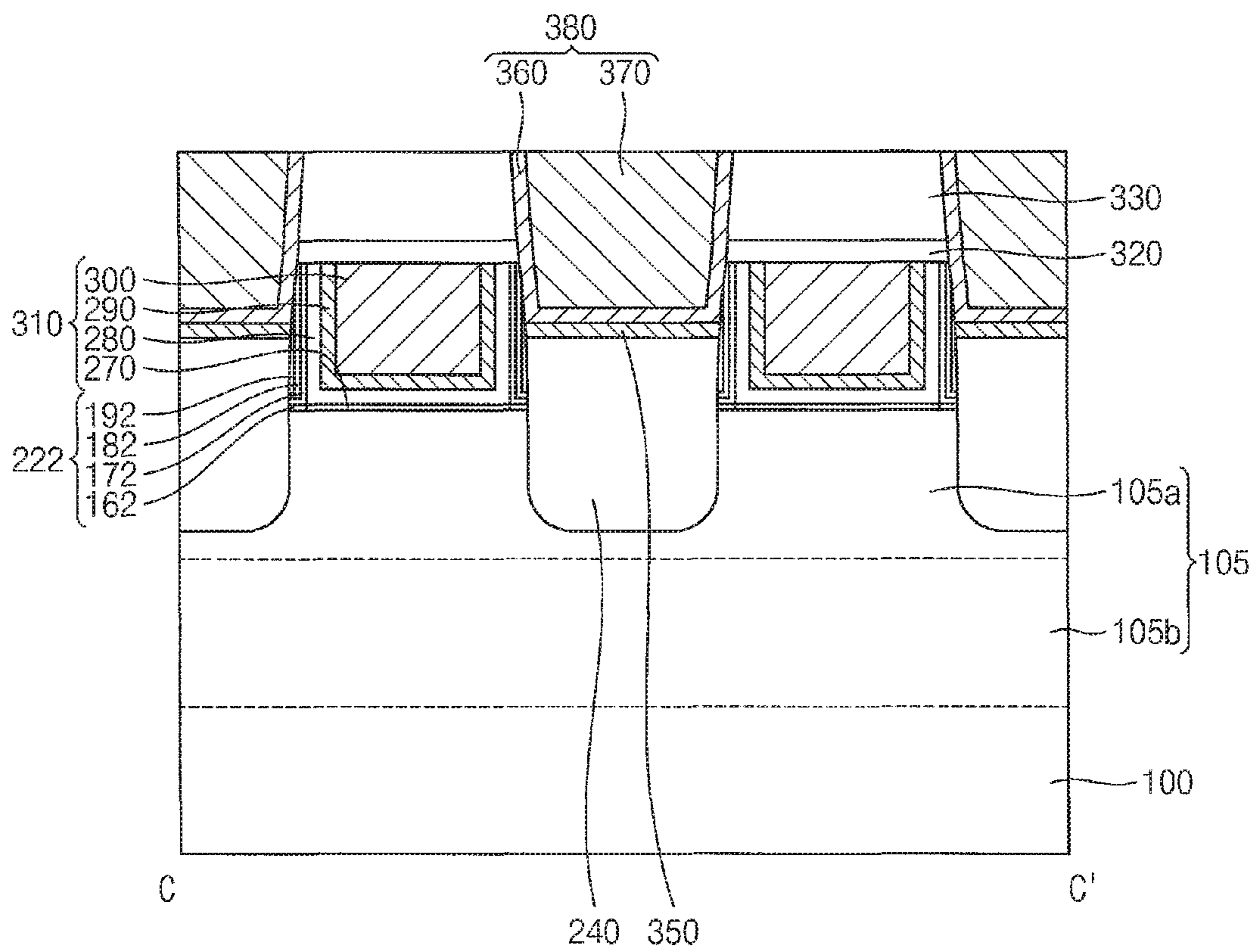


FIG. 38

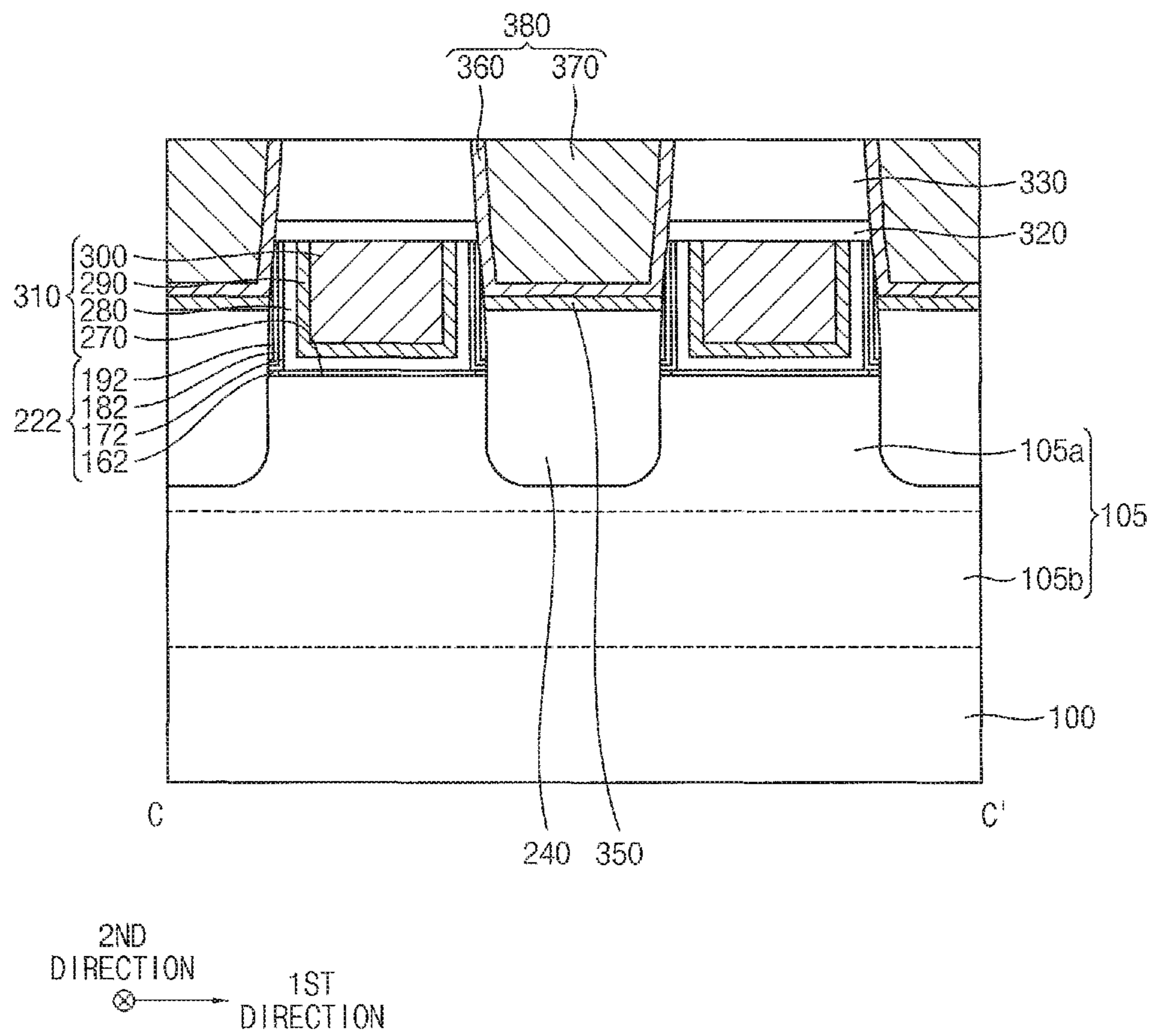


FIG. 39

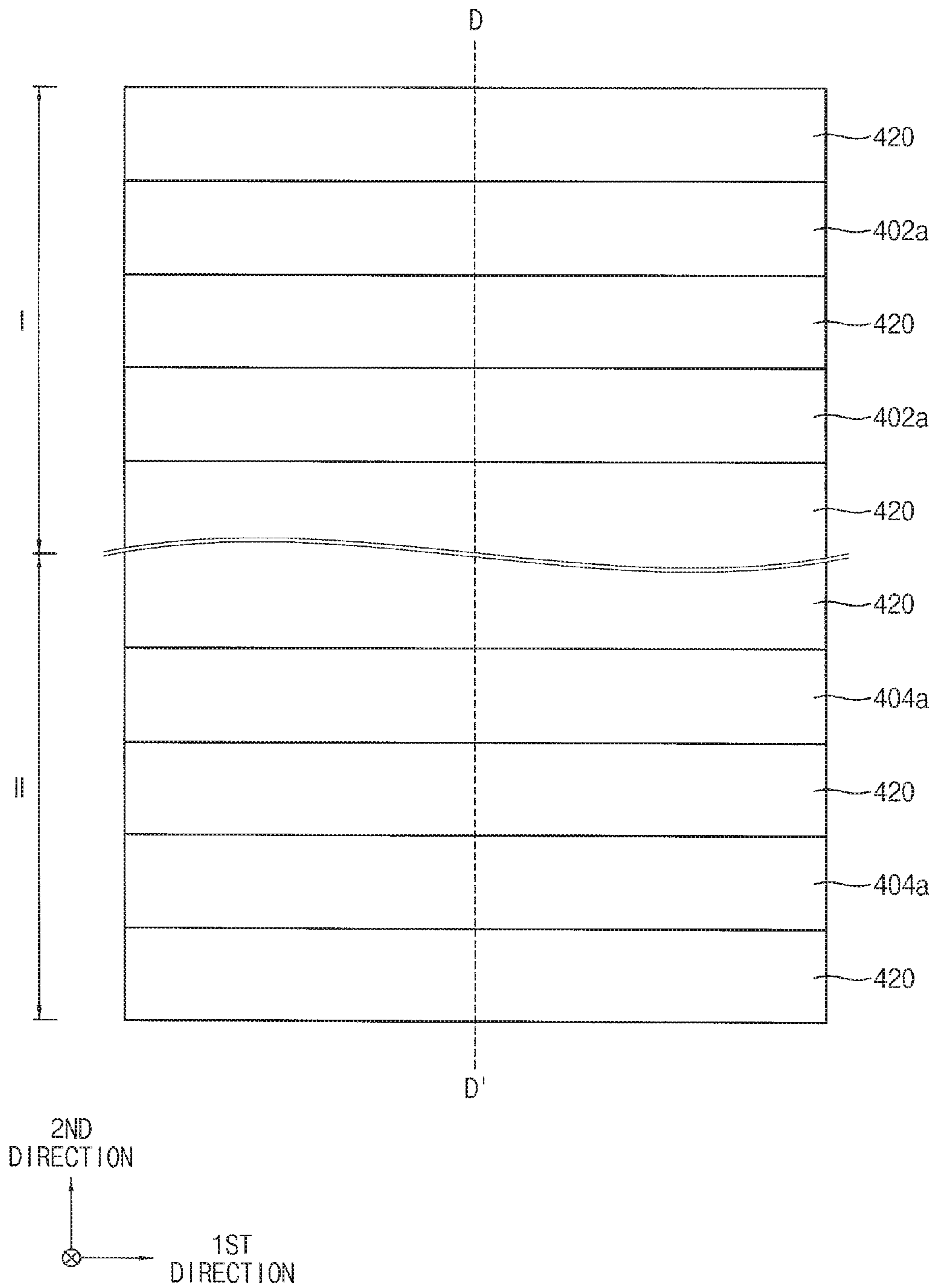




FIG. 40

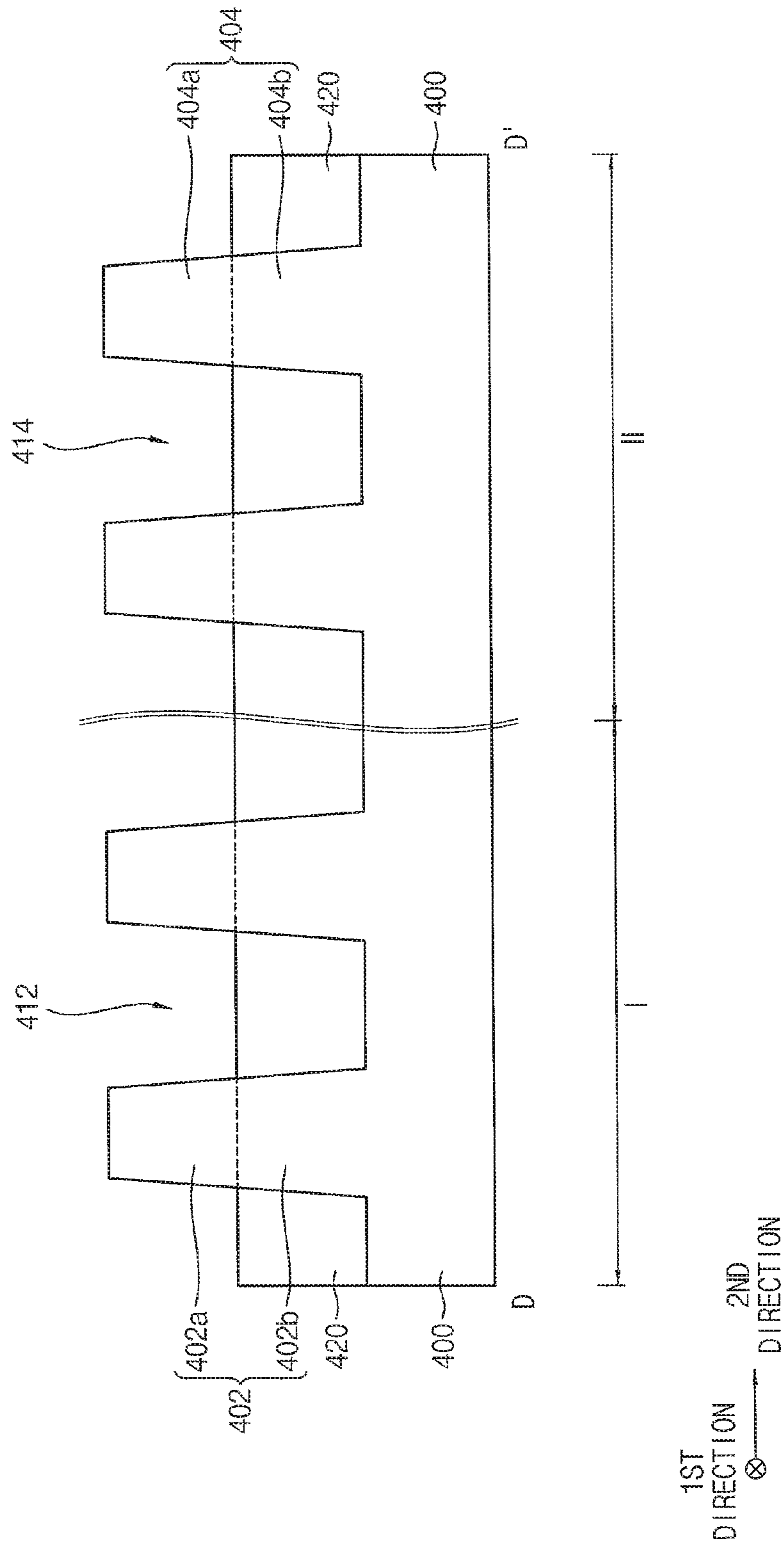


FIG. 41

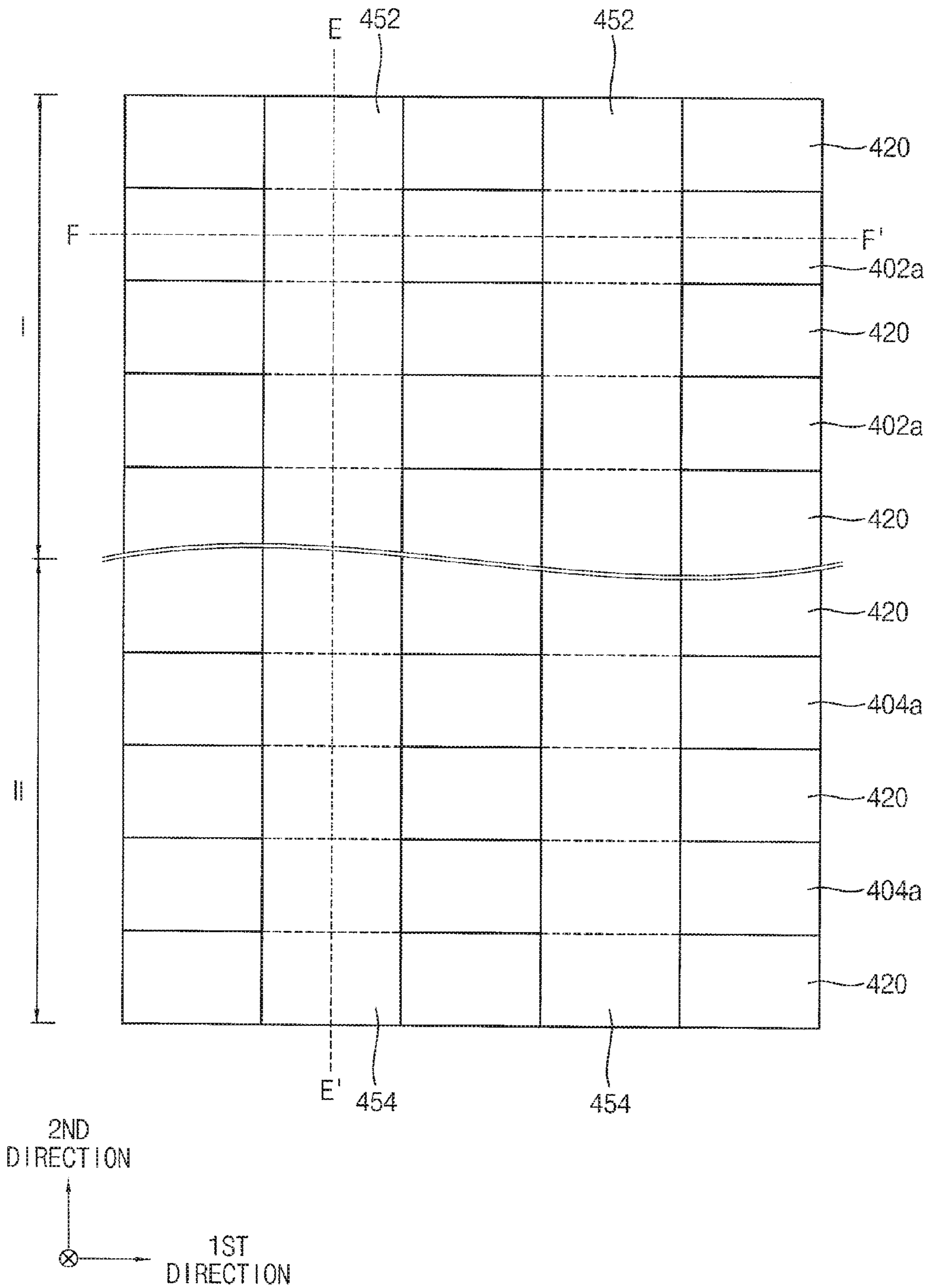


FIG. 42

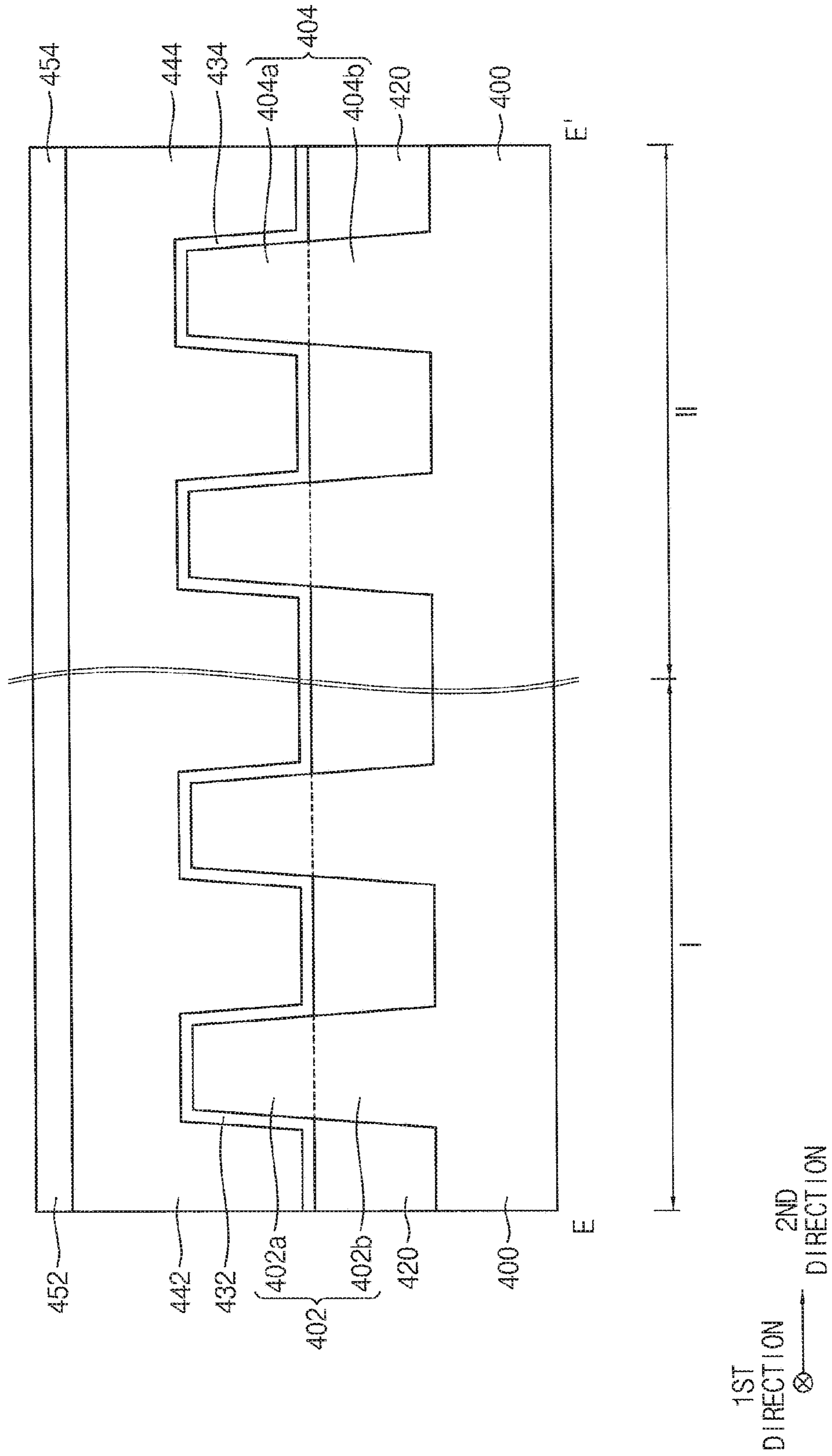


FIG. 43

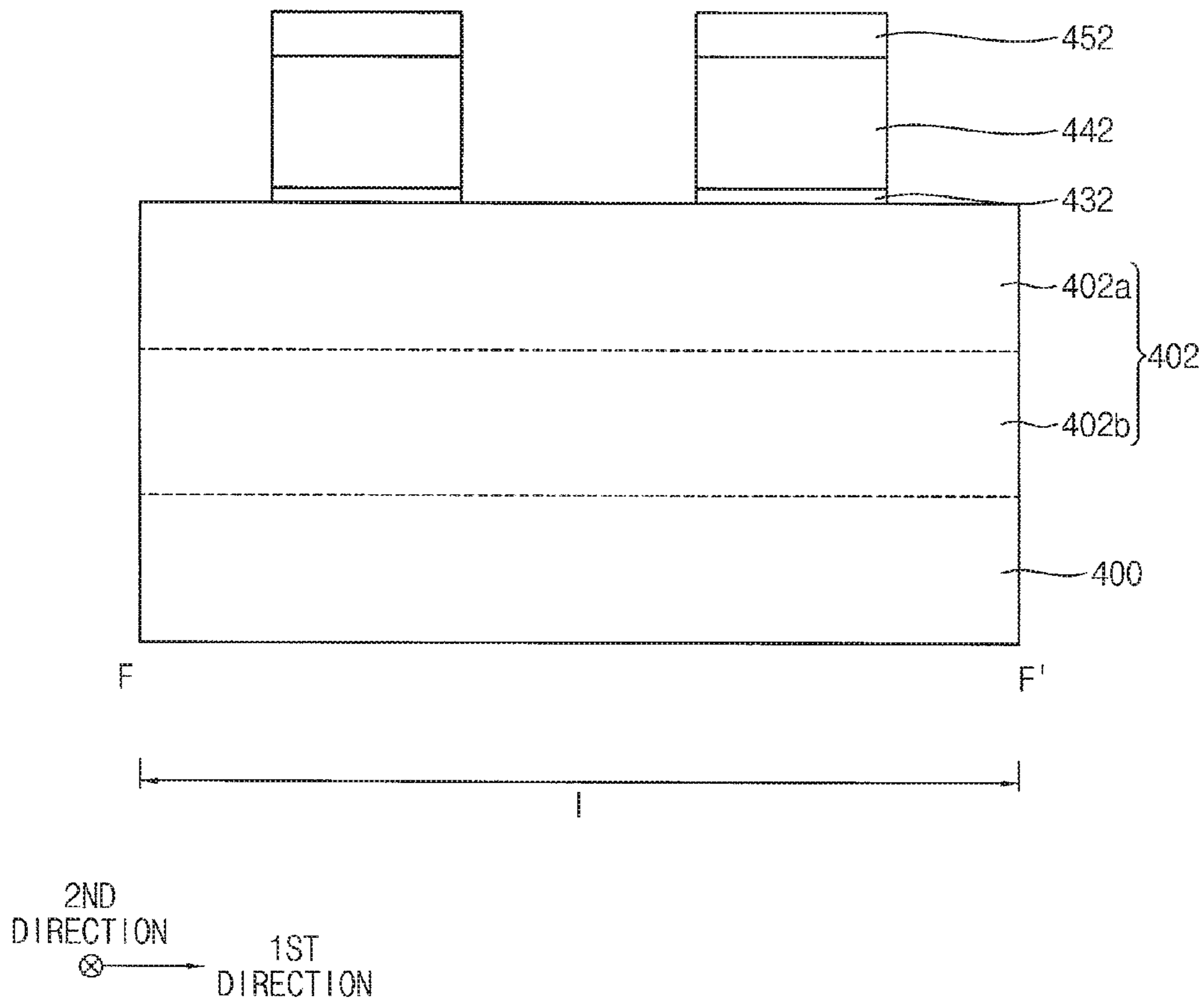


FIG. 44

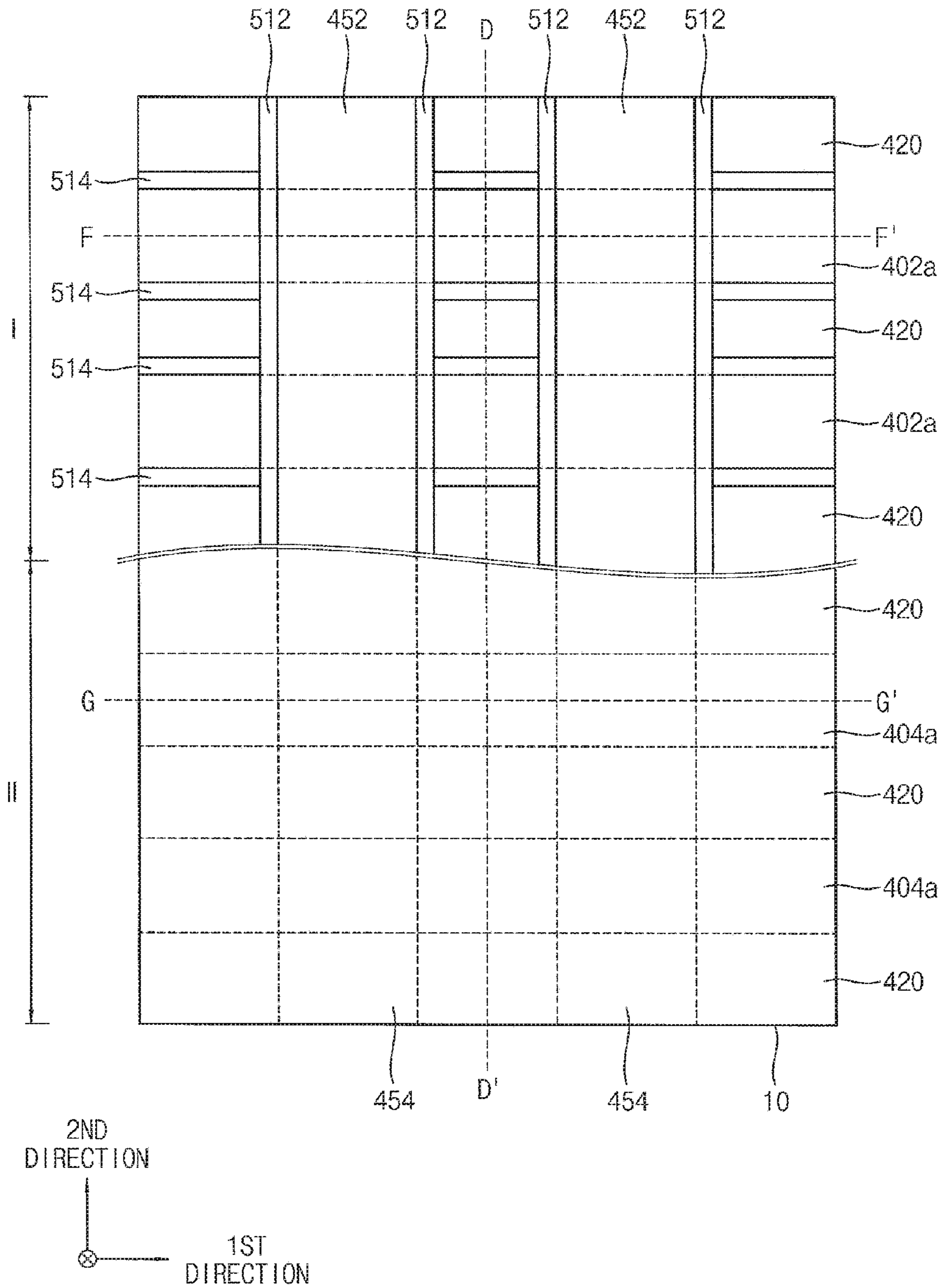


FIG. 45

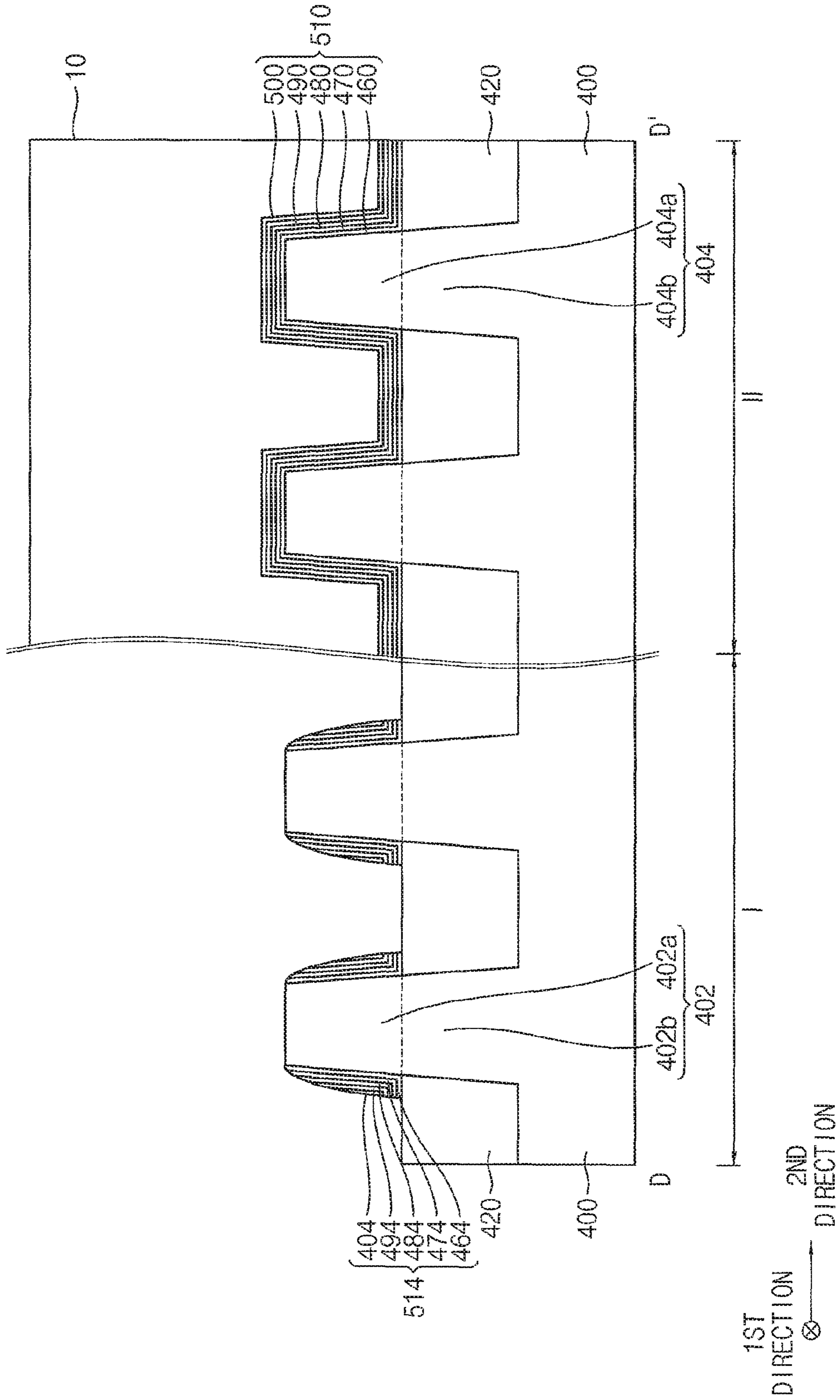




FIG. 46

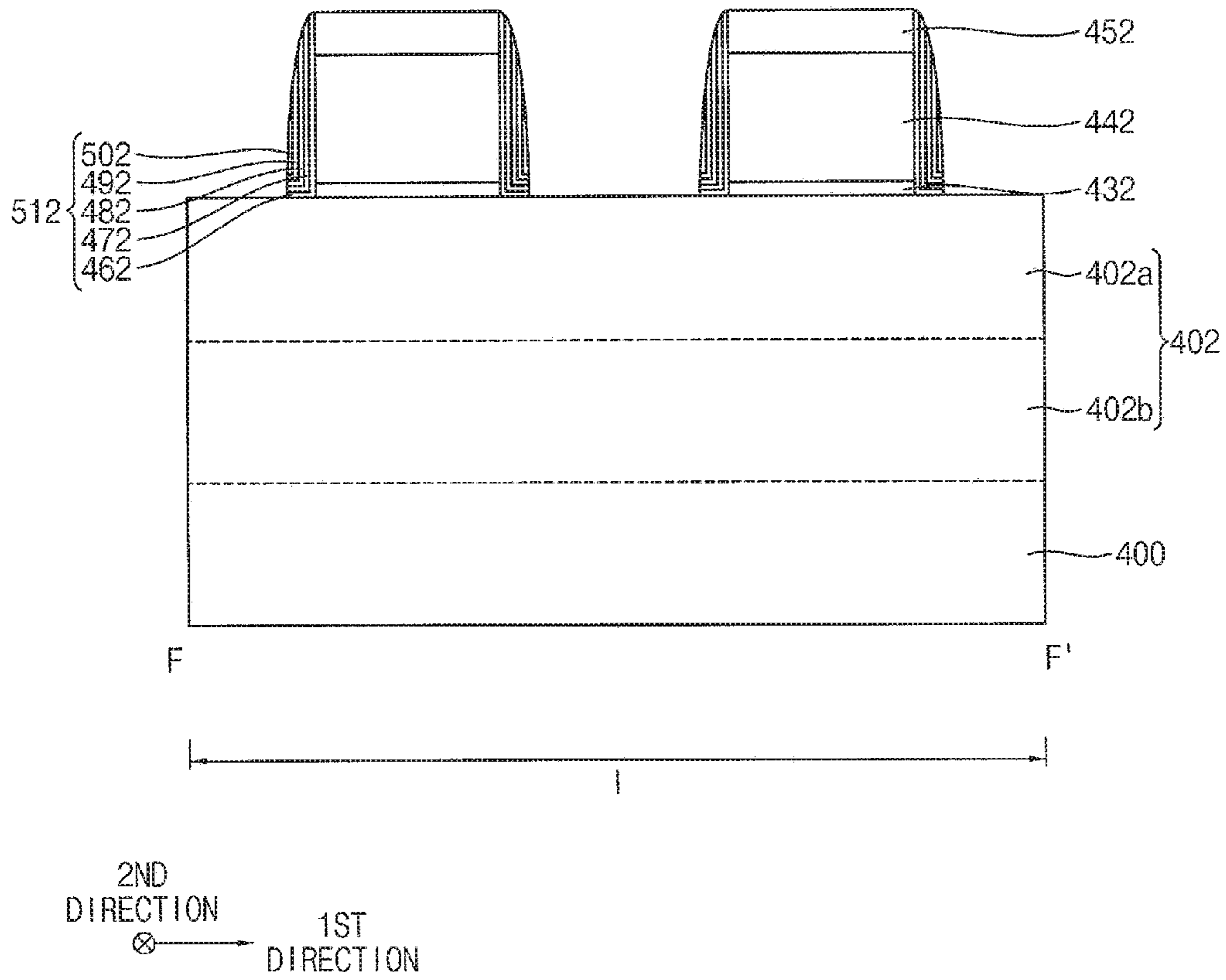


FIG. 47

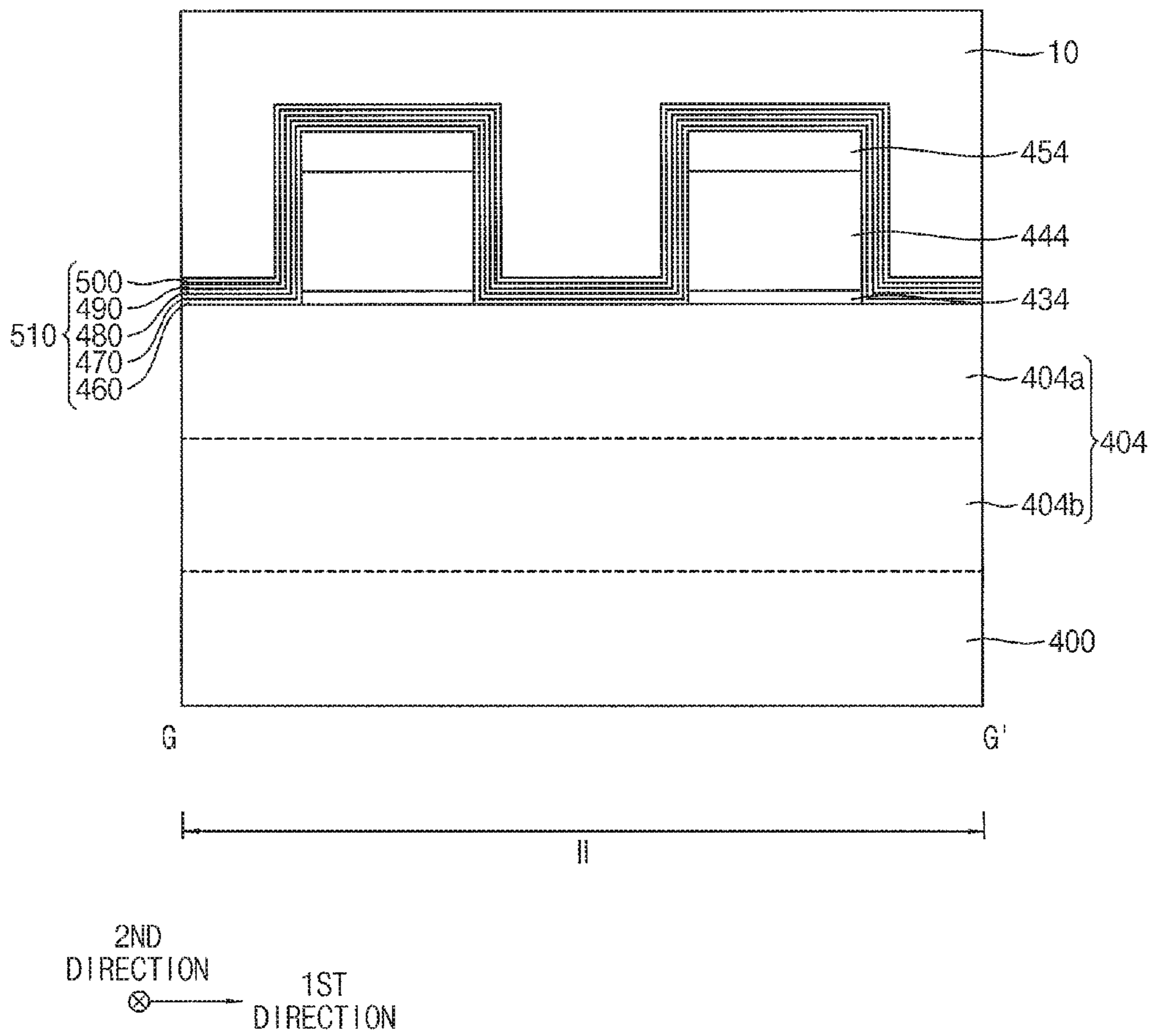


FIG. 48

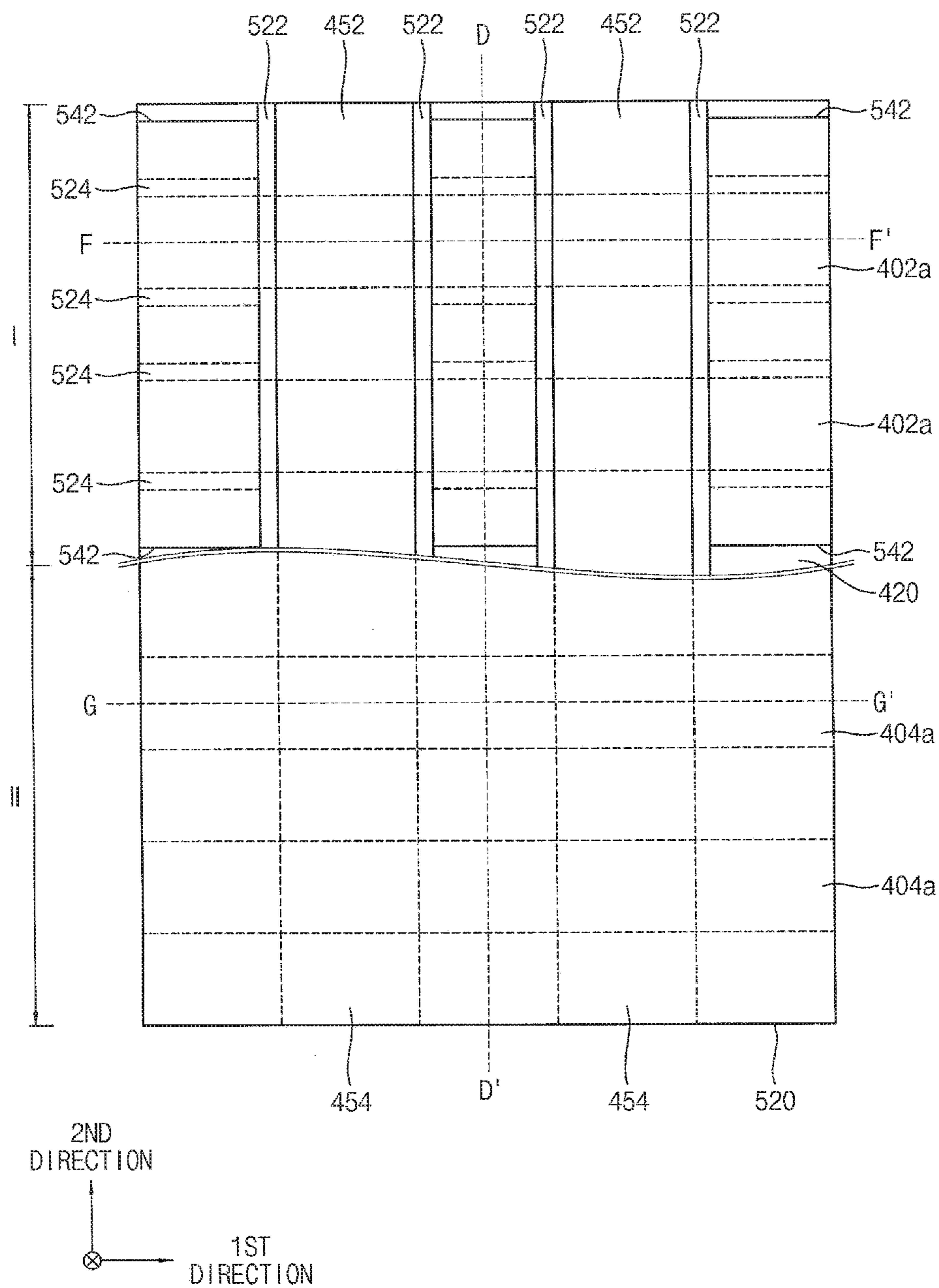


FIG. 49

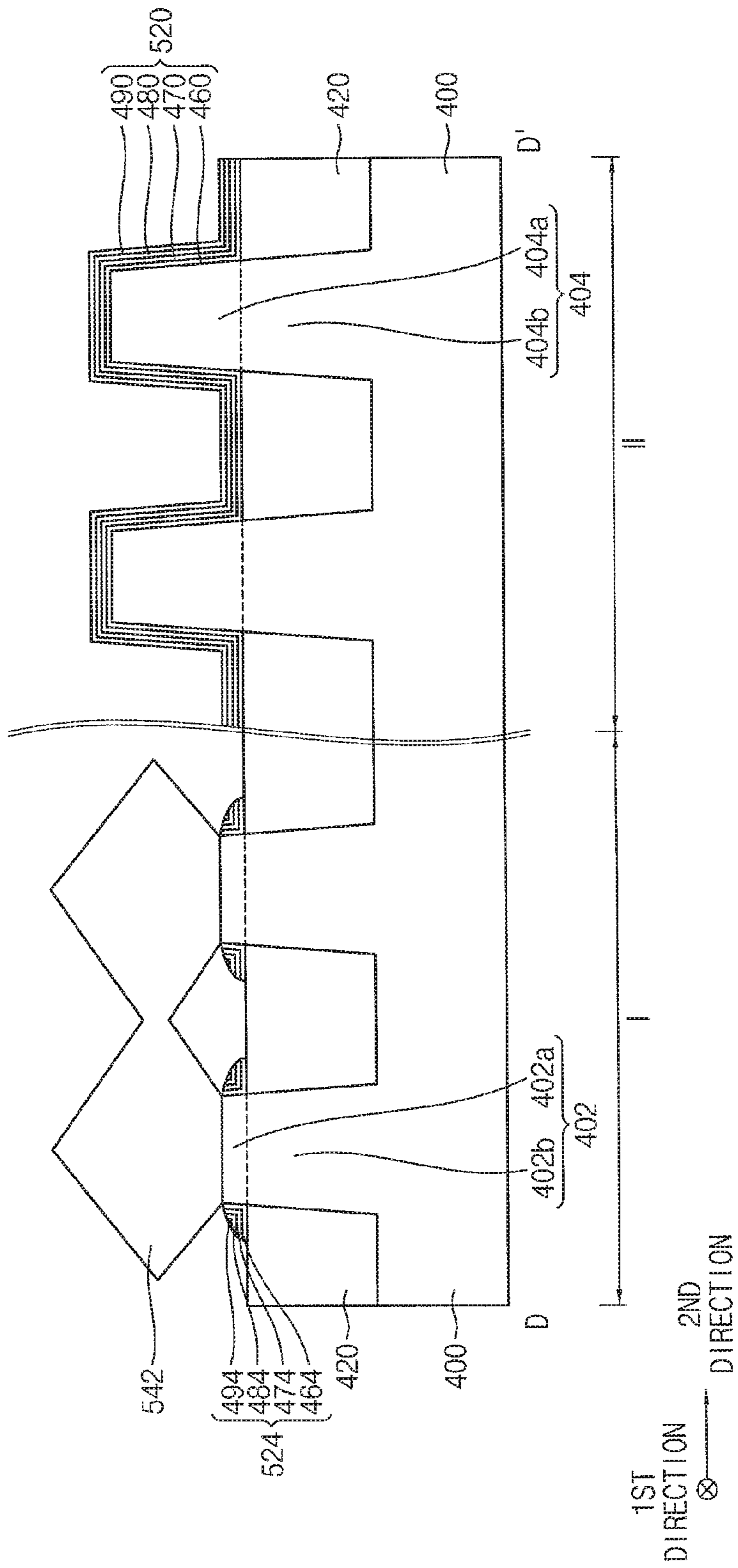


FIG. 50

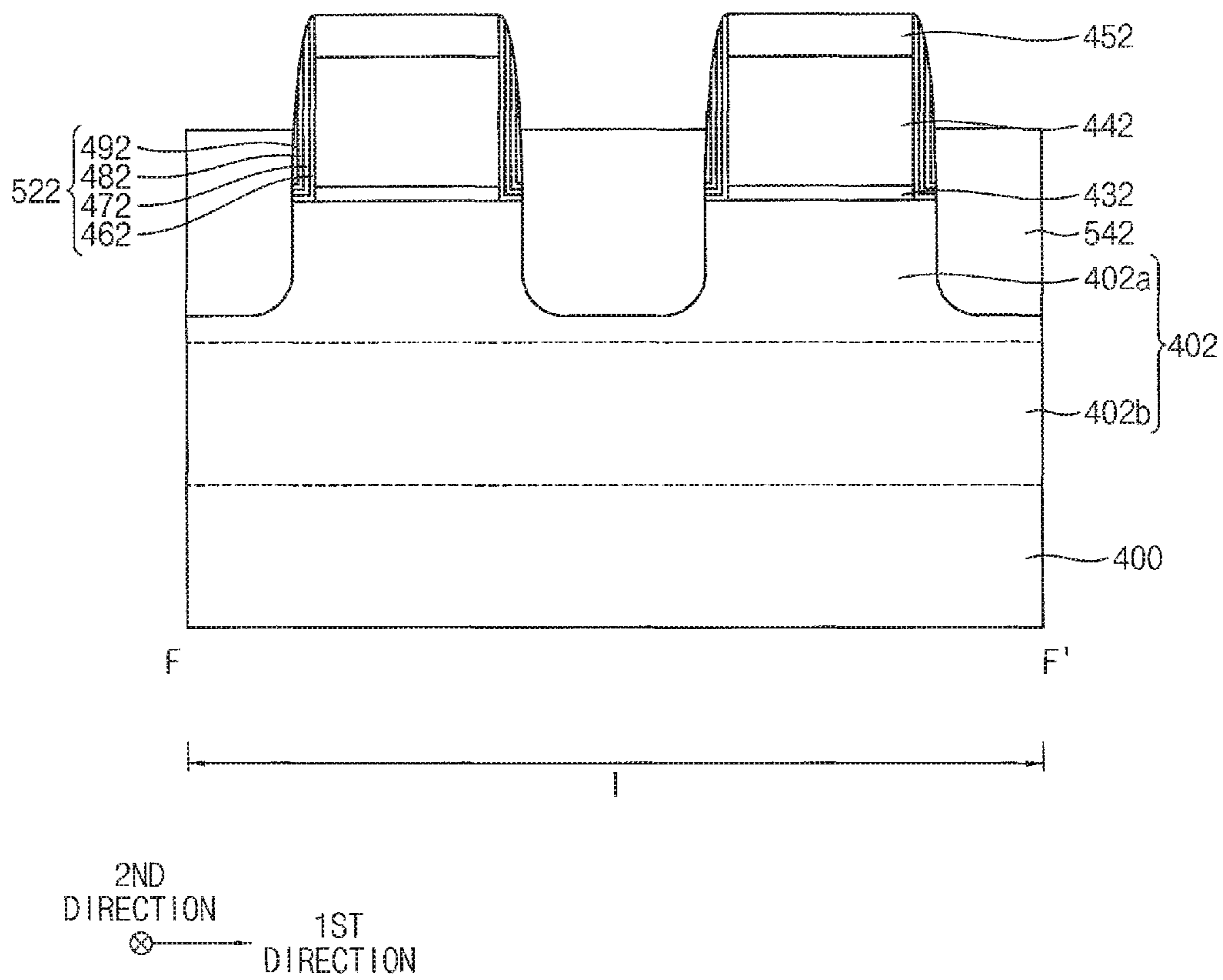


FIG. 51

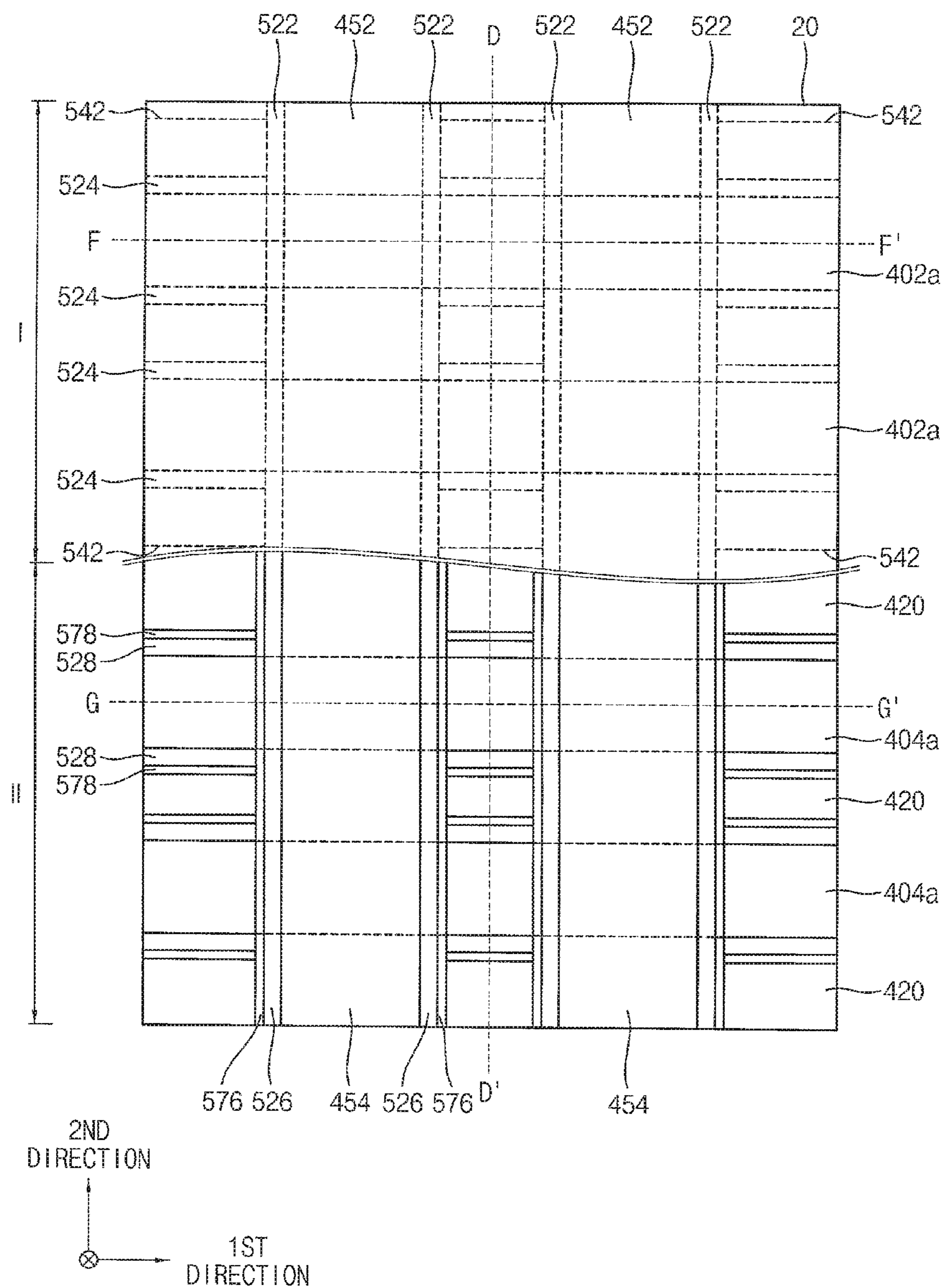




FIG. 52

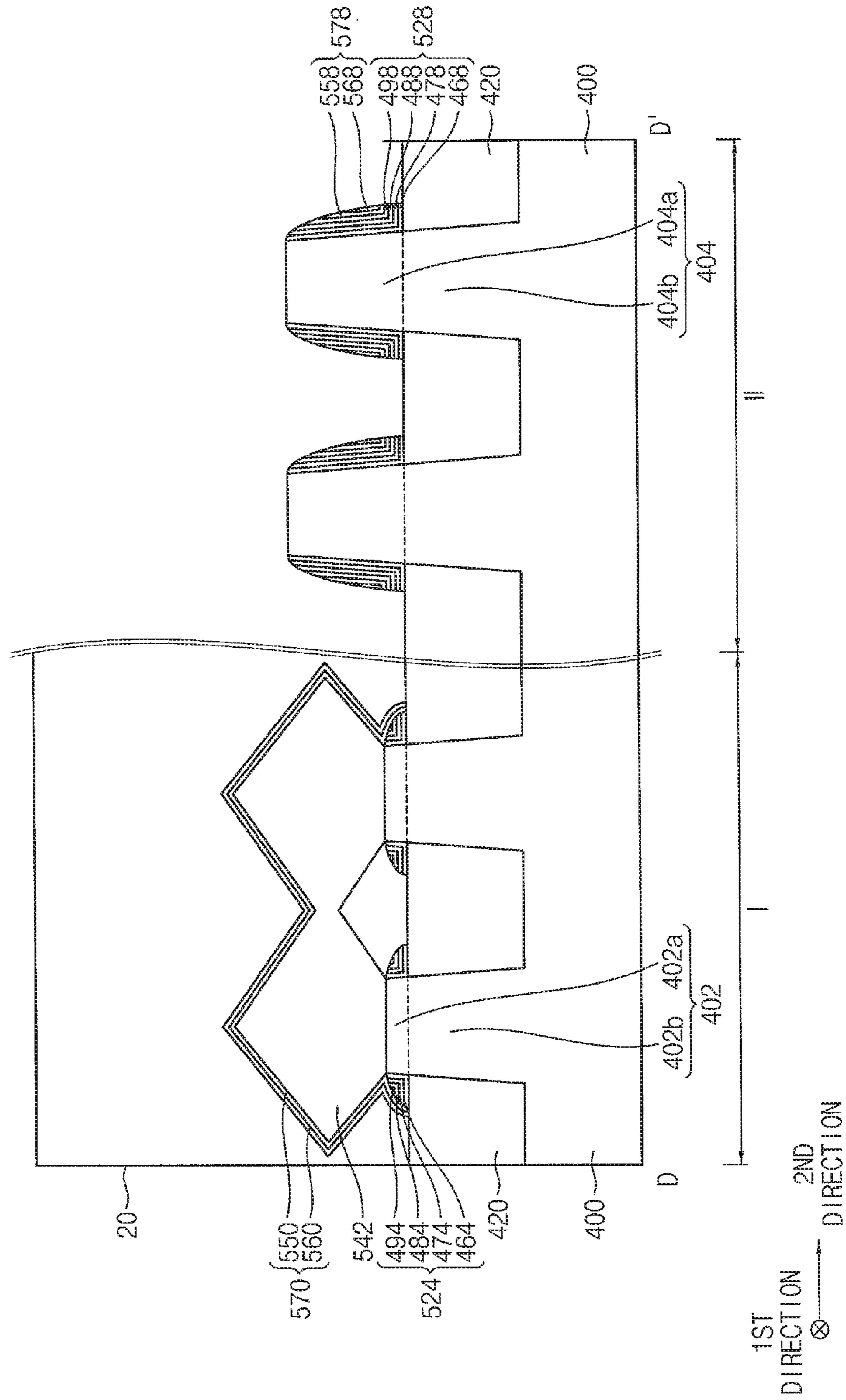


FIG. 53

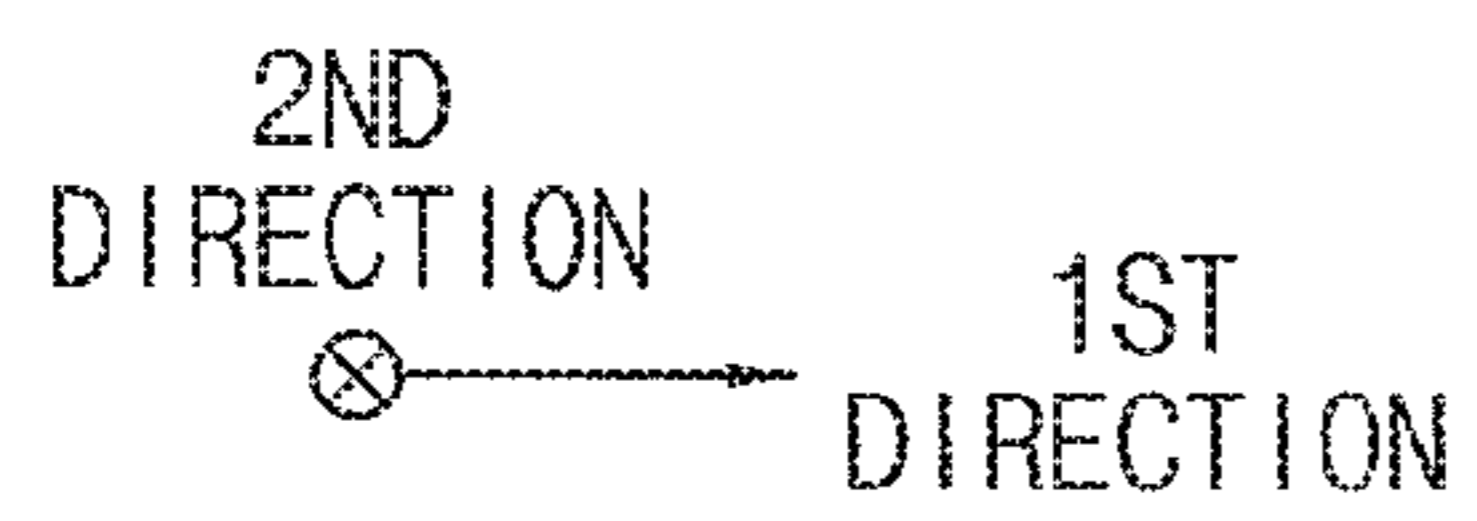
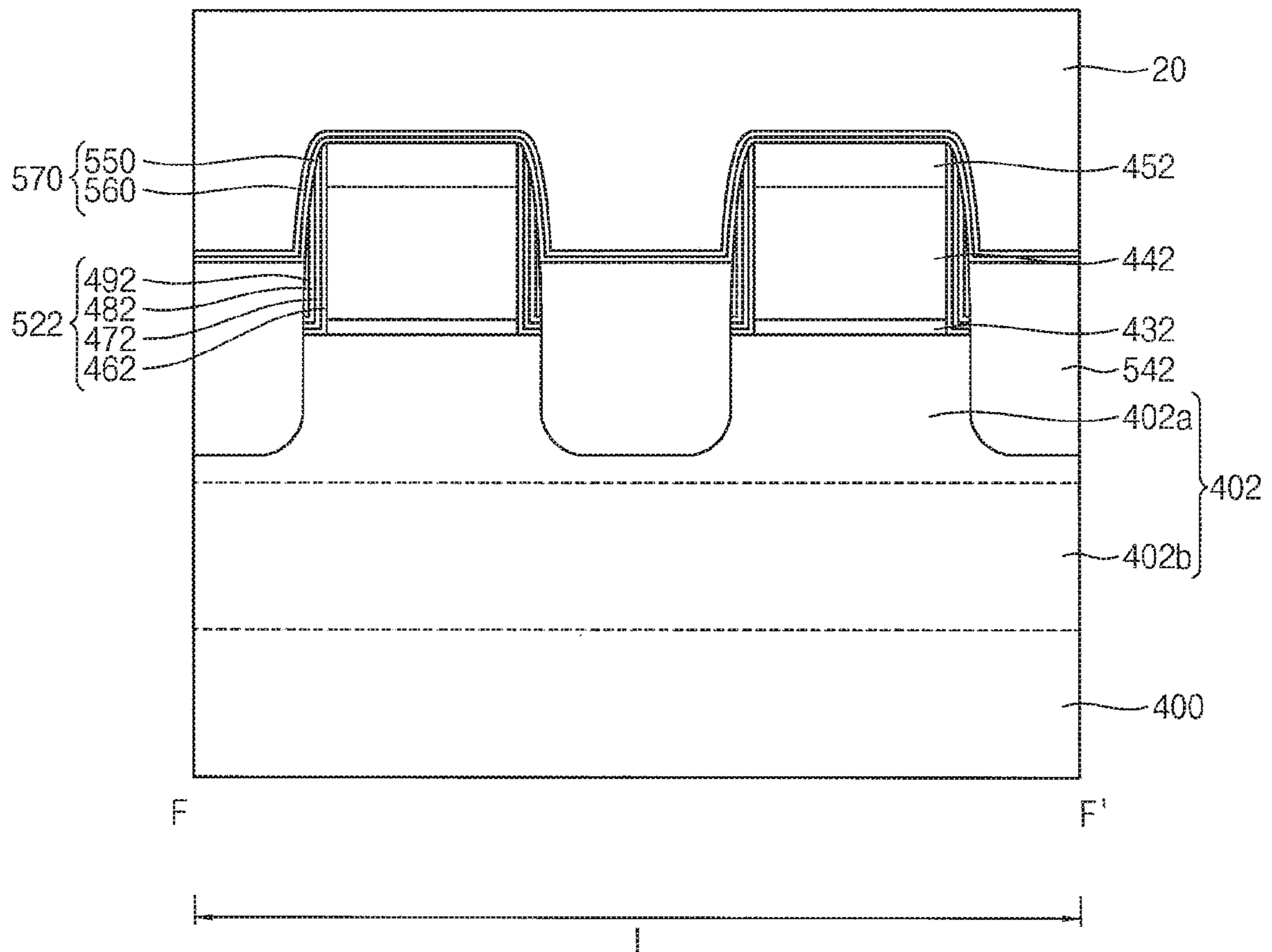


FIG. 54

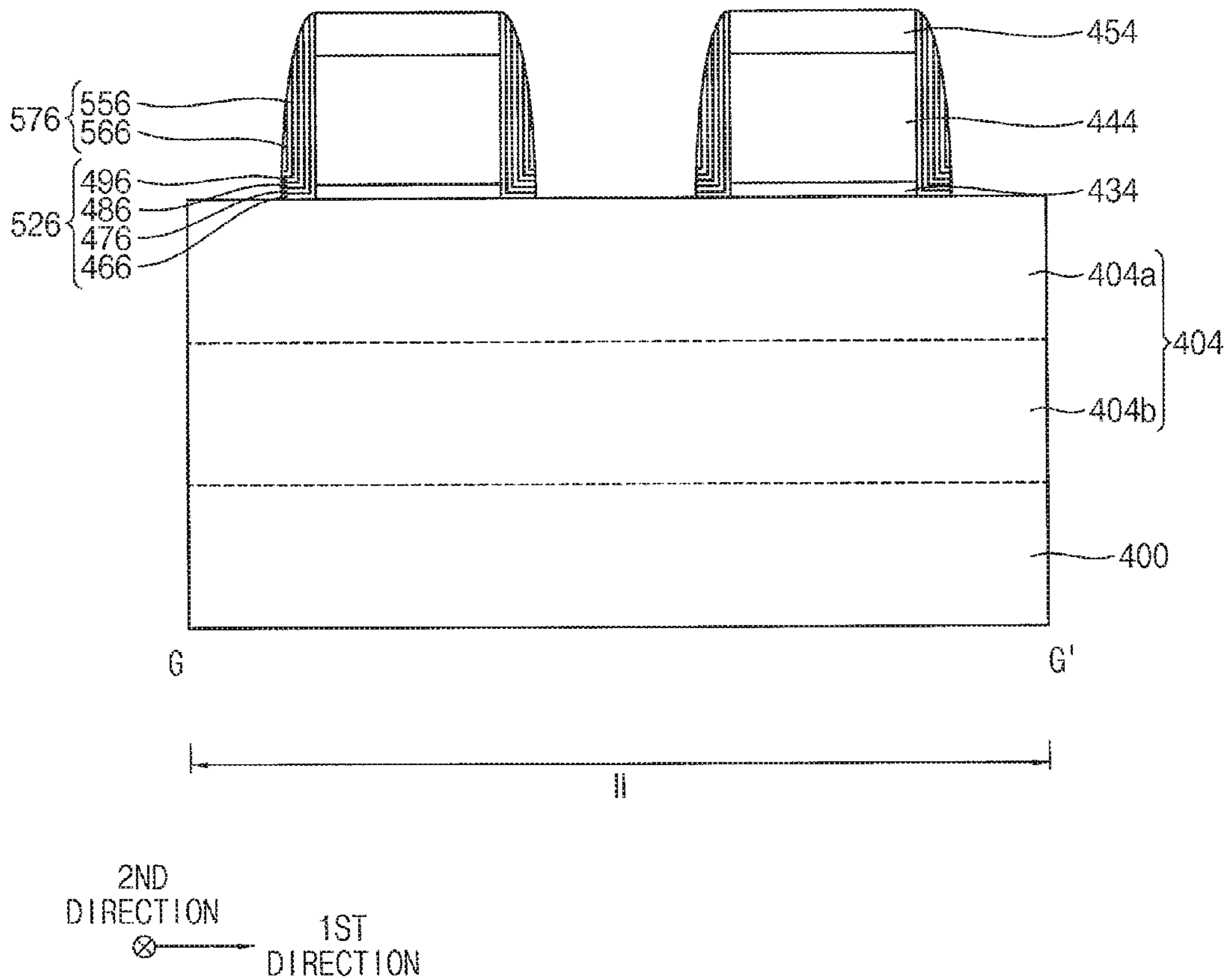


FIG. 55

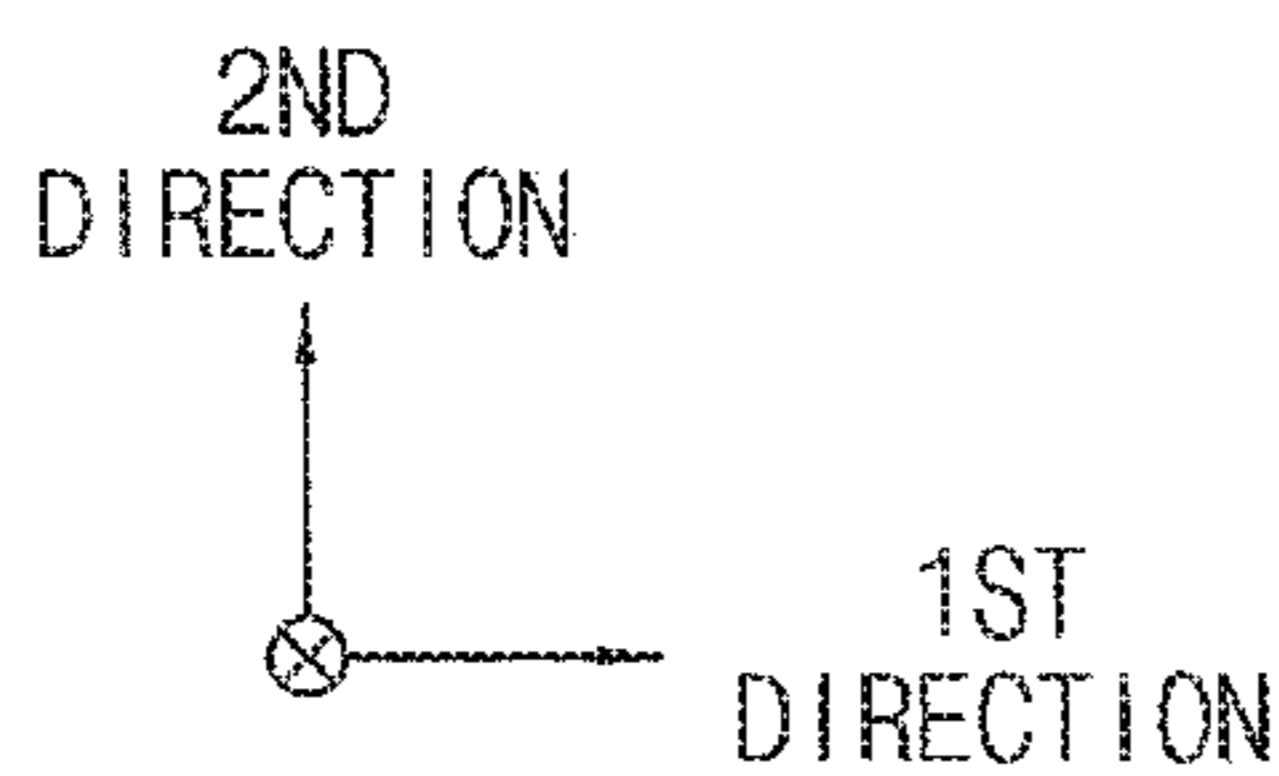
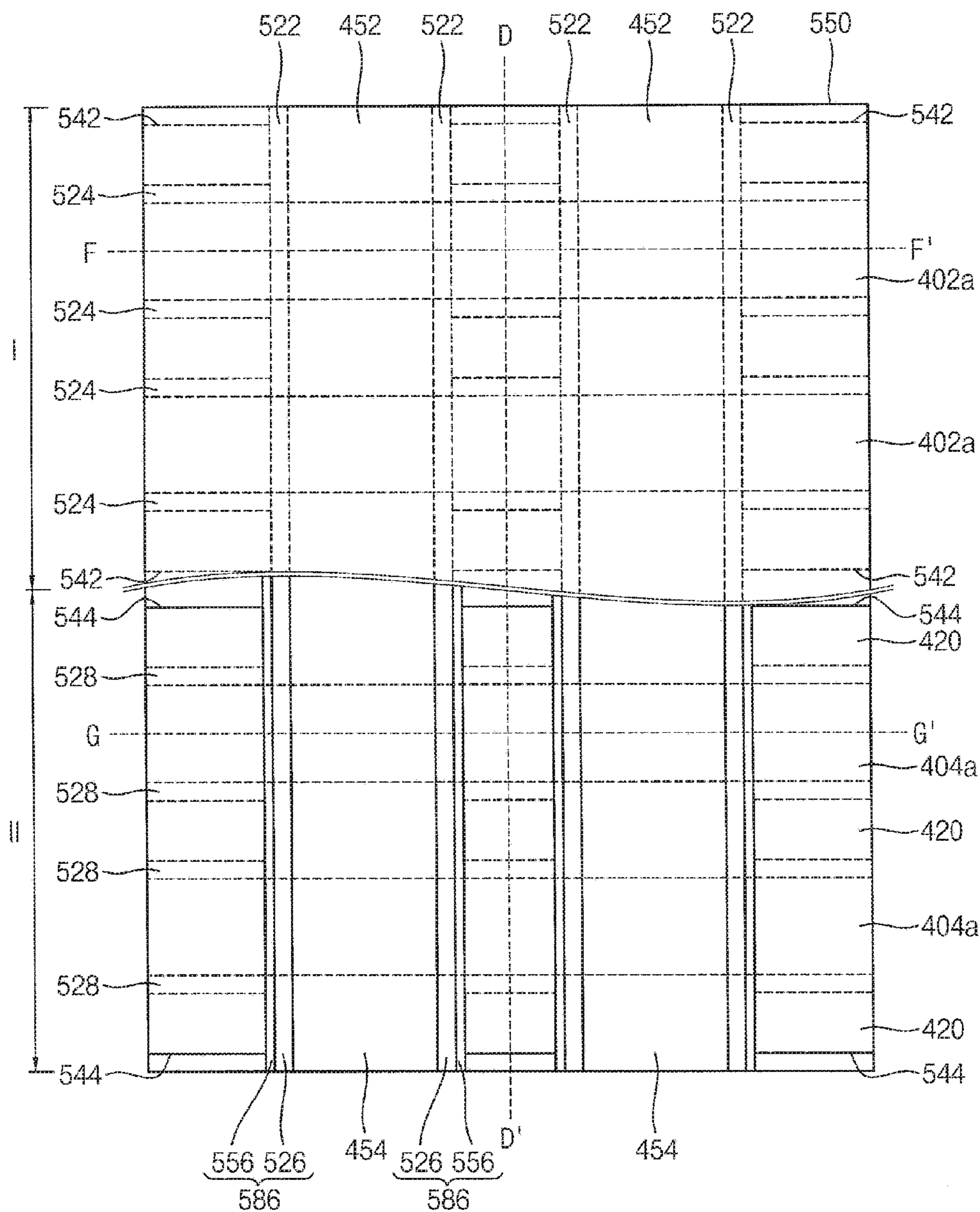


FIG. 56

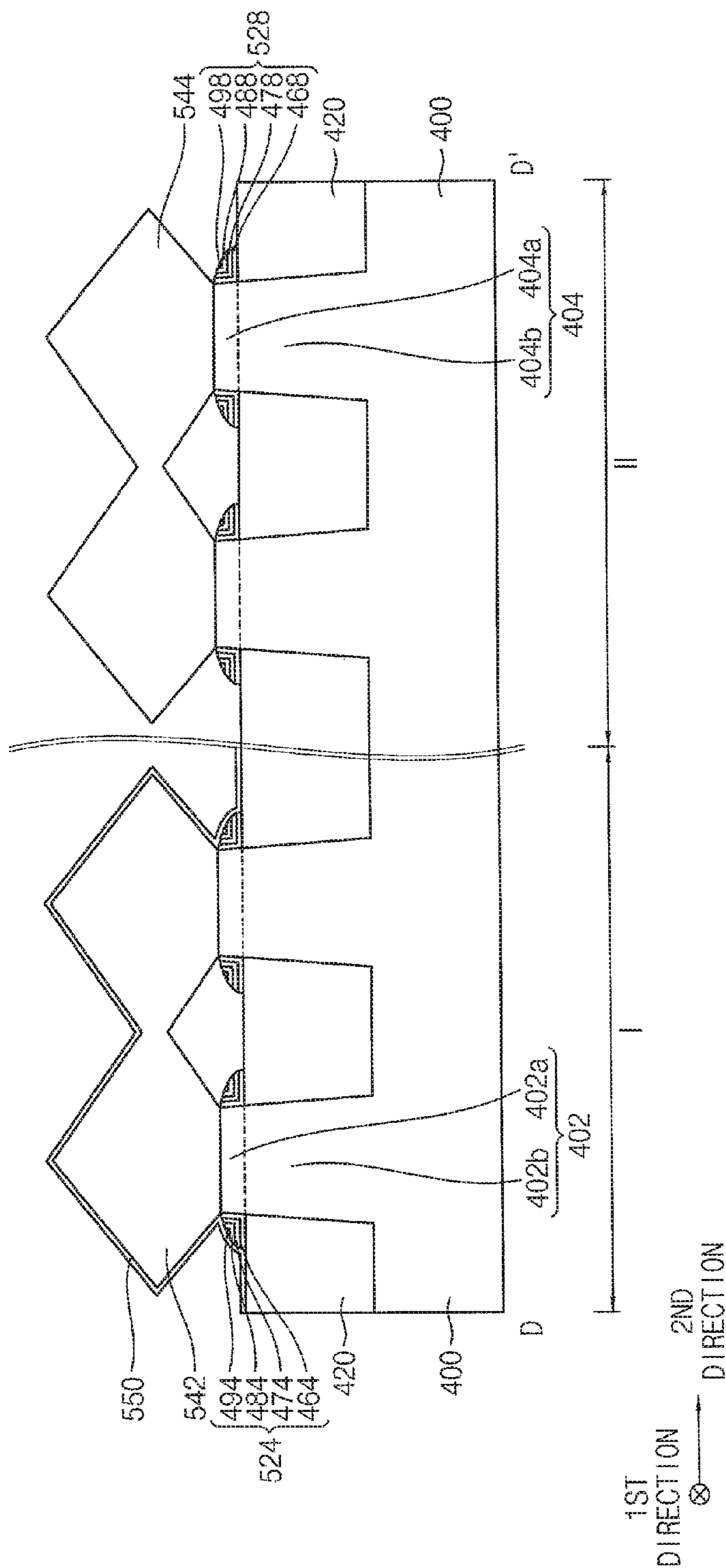




FIG. 57

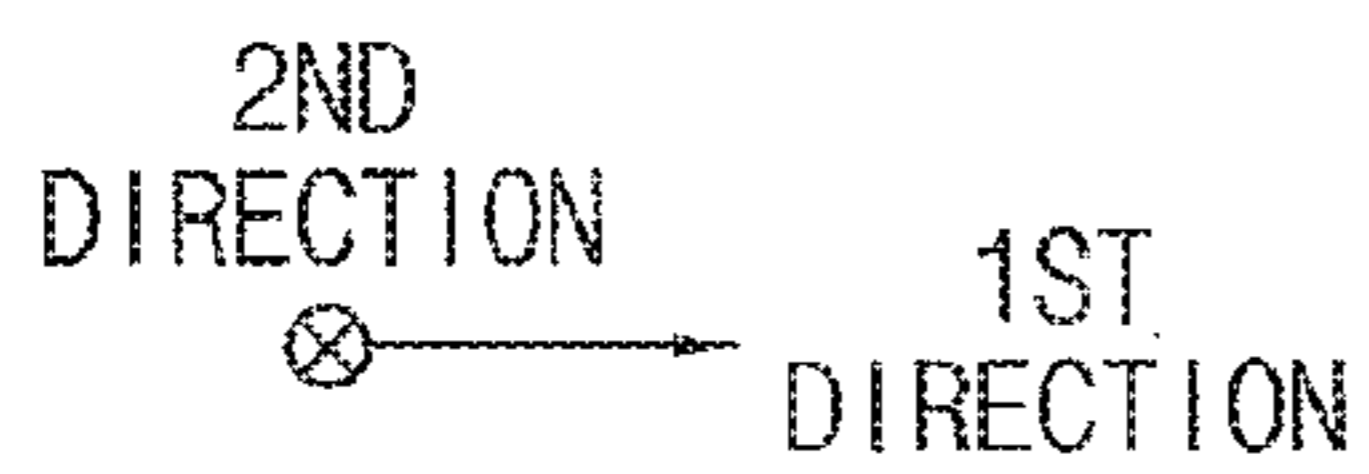
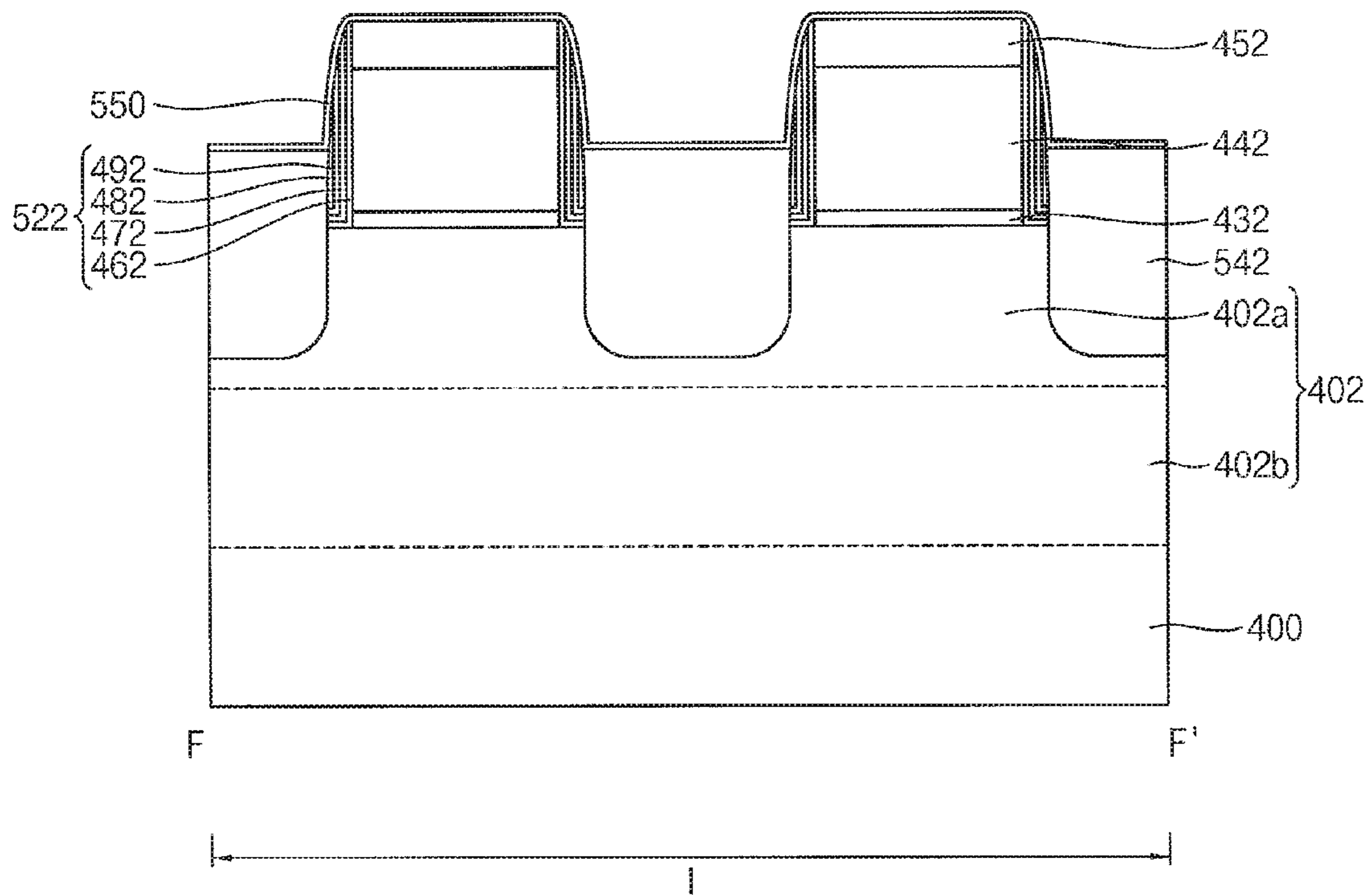




FIG. 58

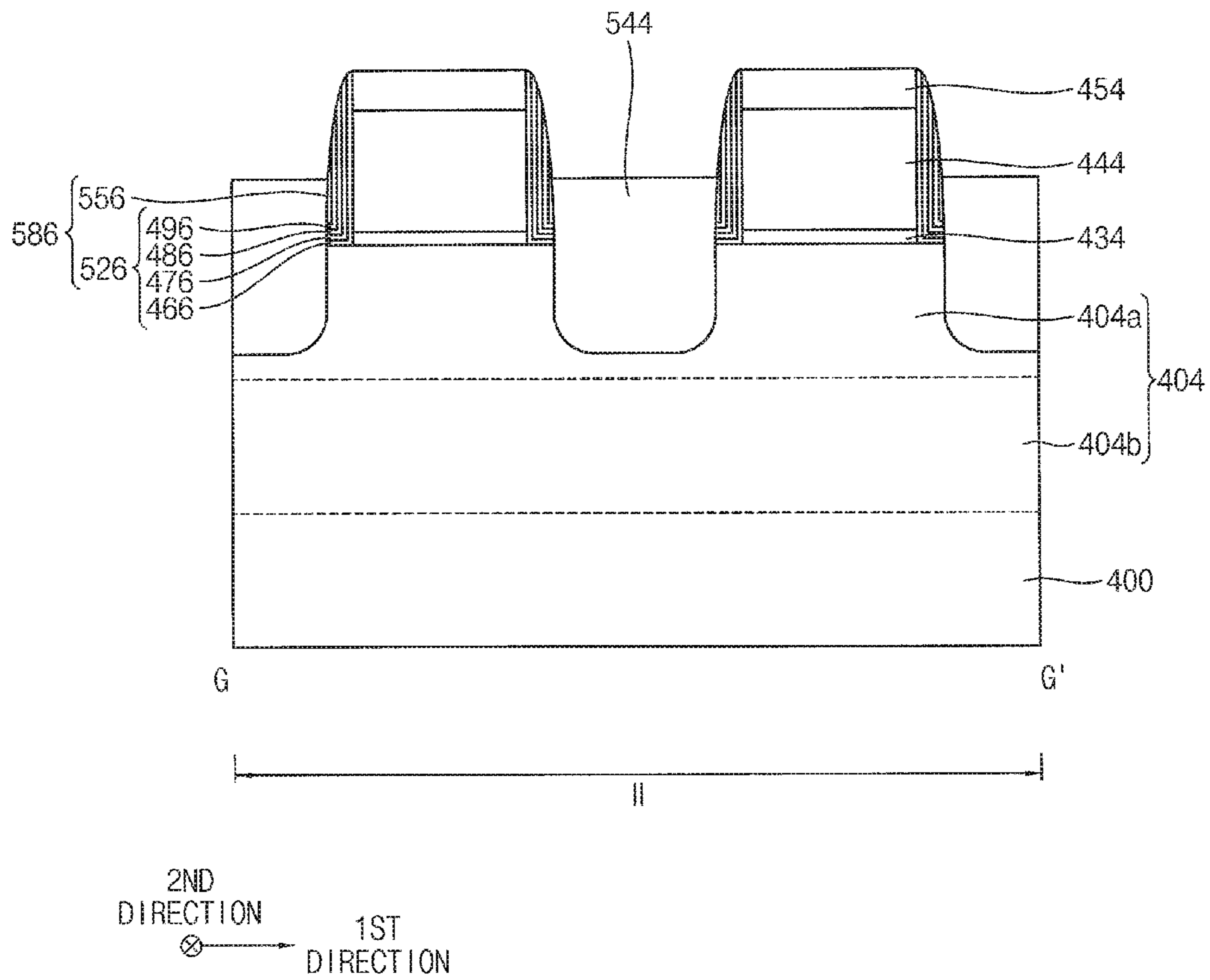


FIG. 59

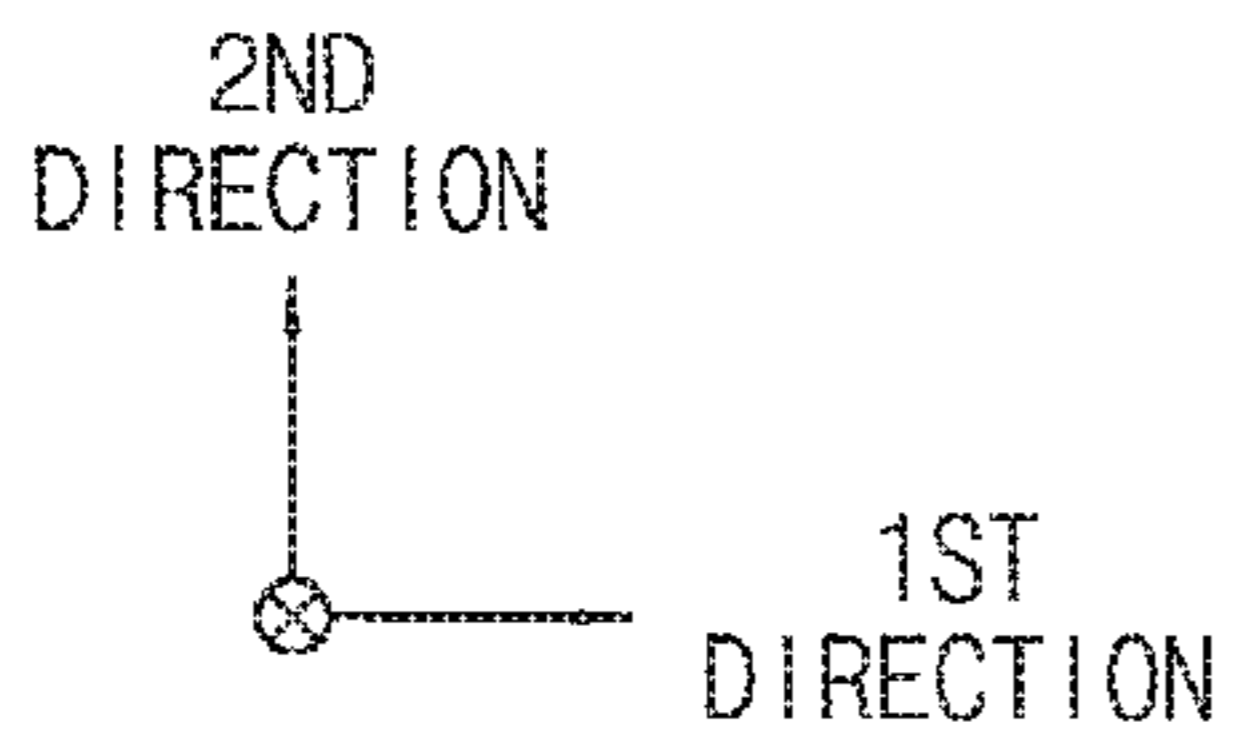
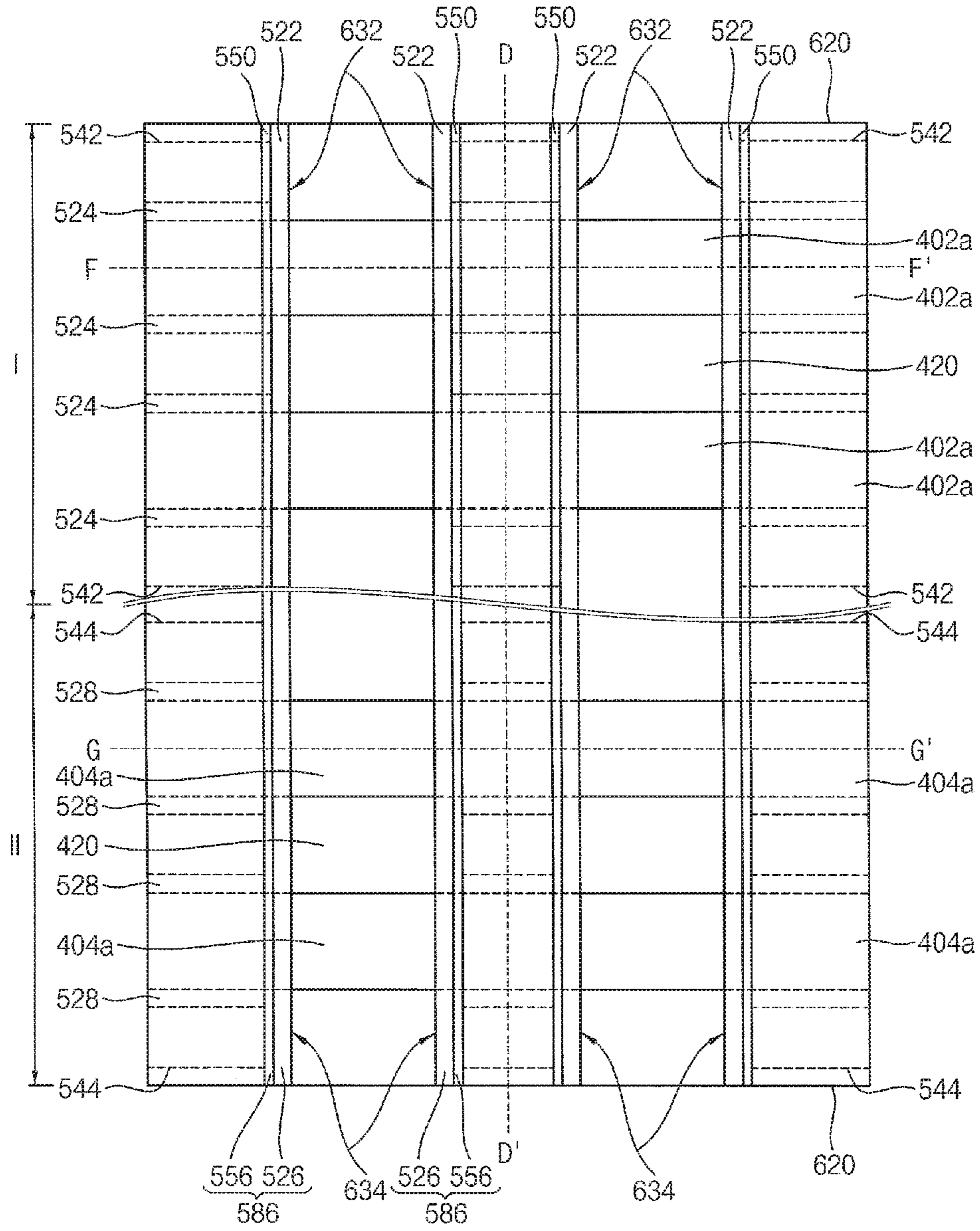


FIG. 60

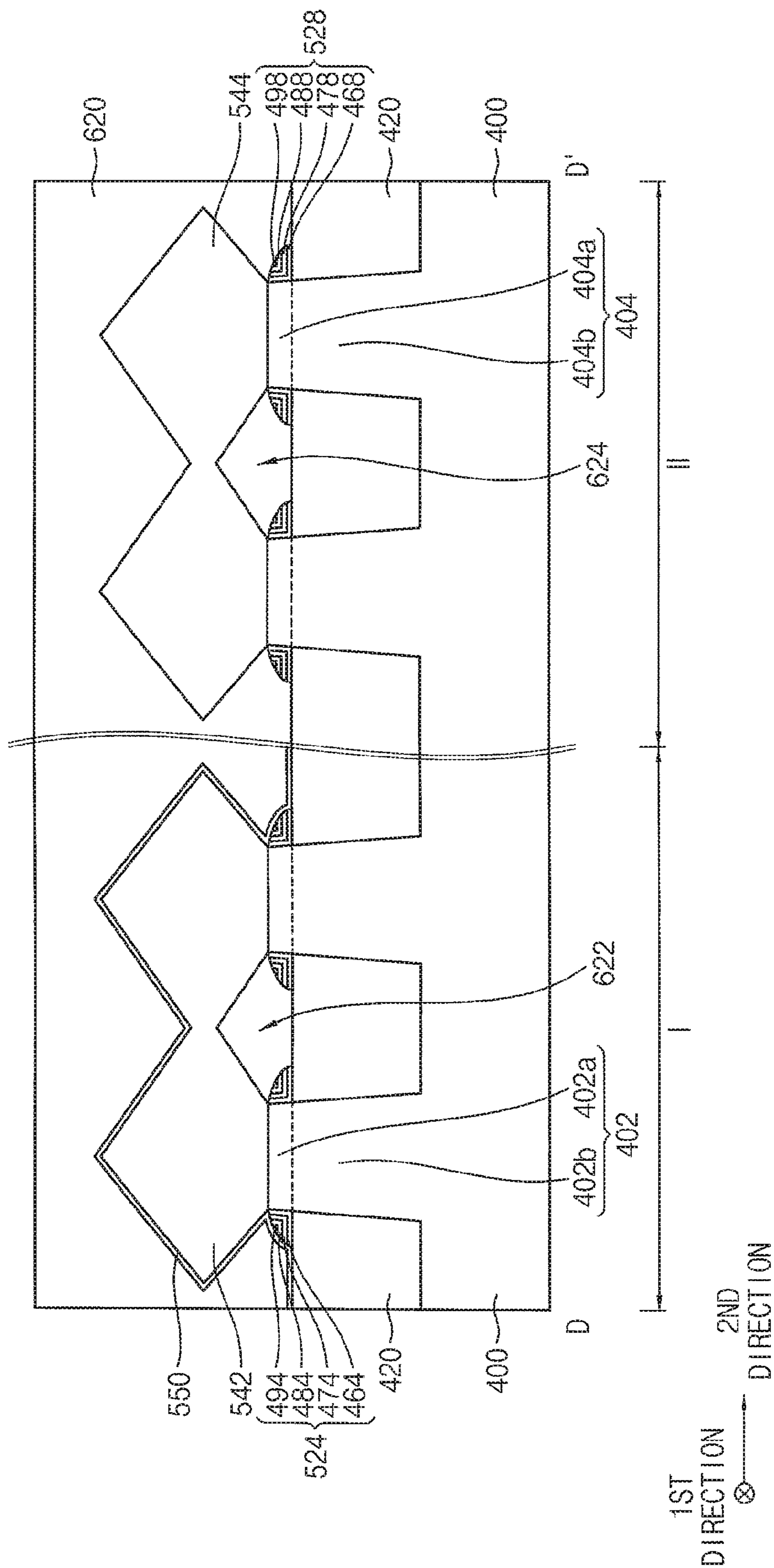


FIG. 61

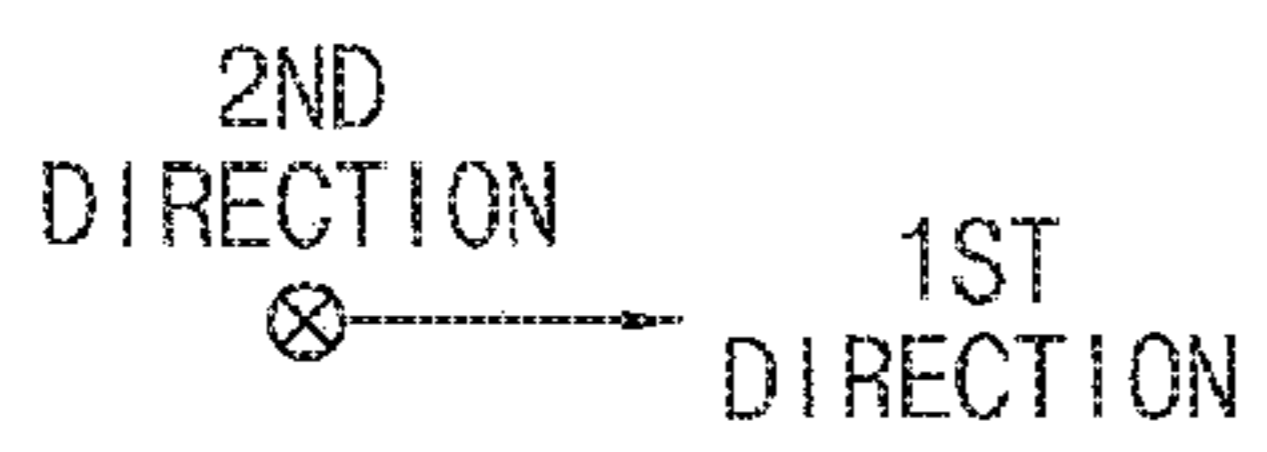
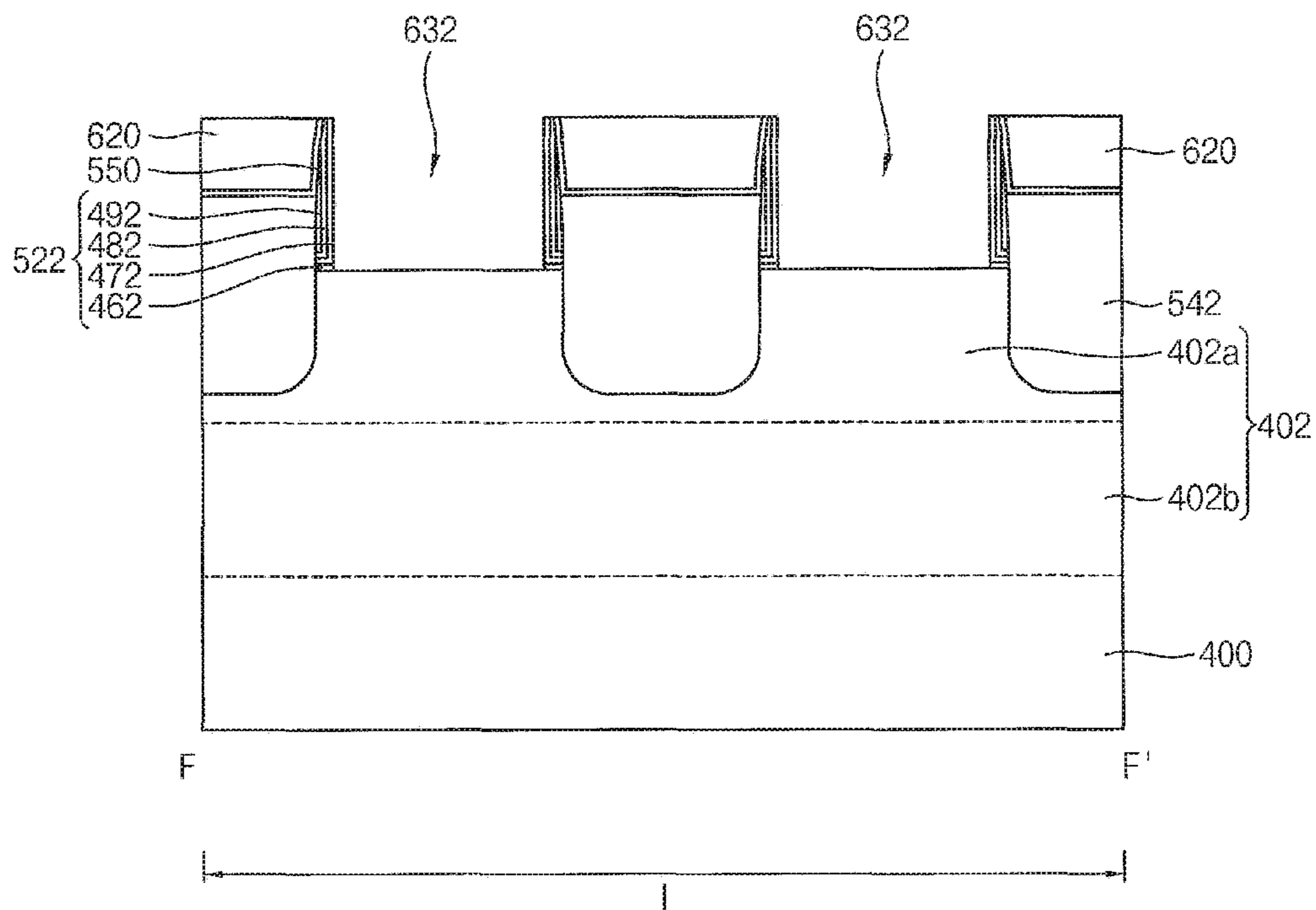


FIG. 62

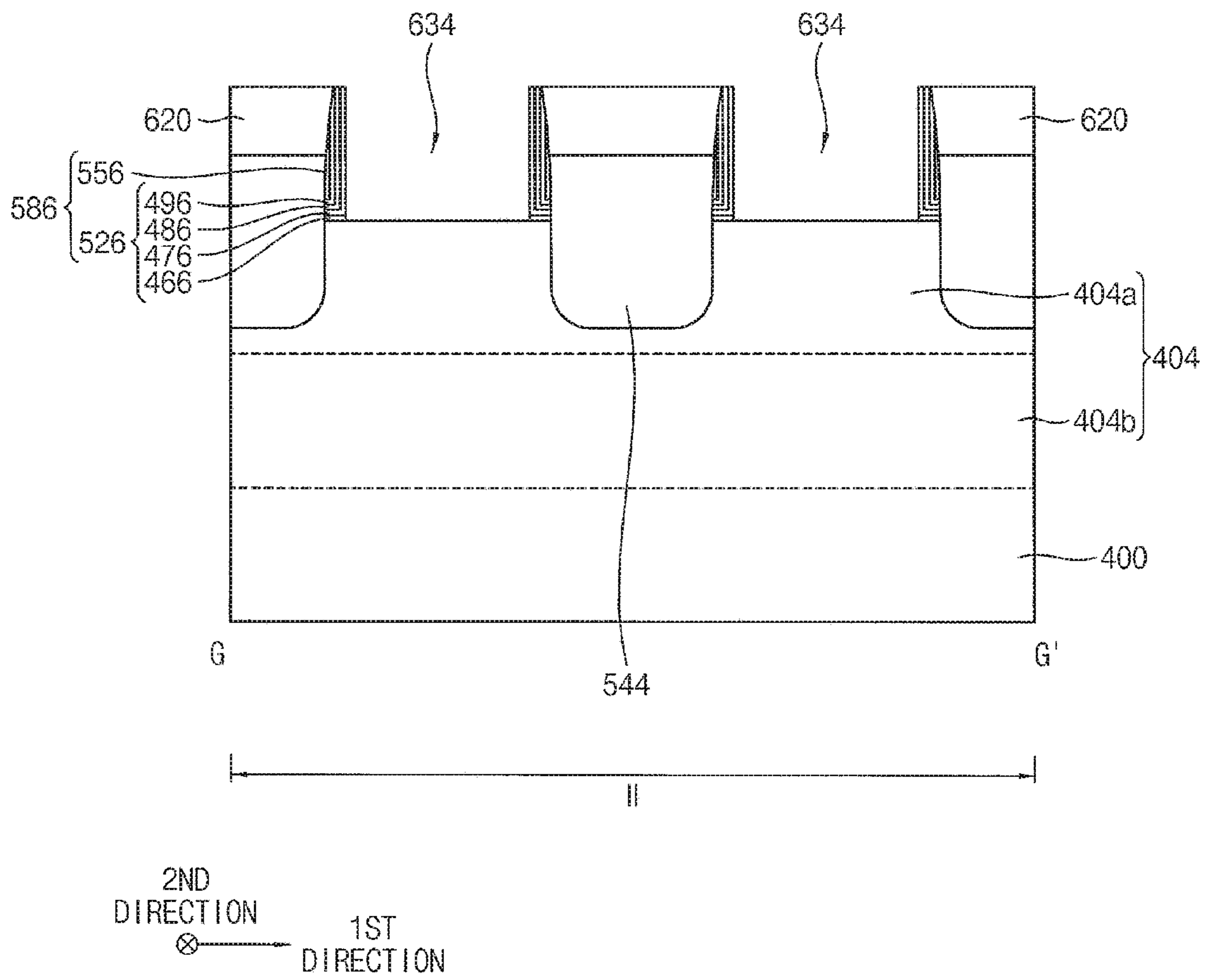




FIG. 63

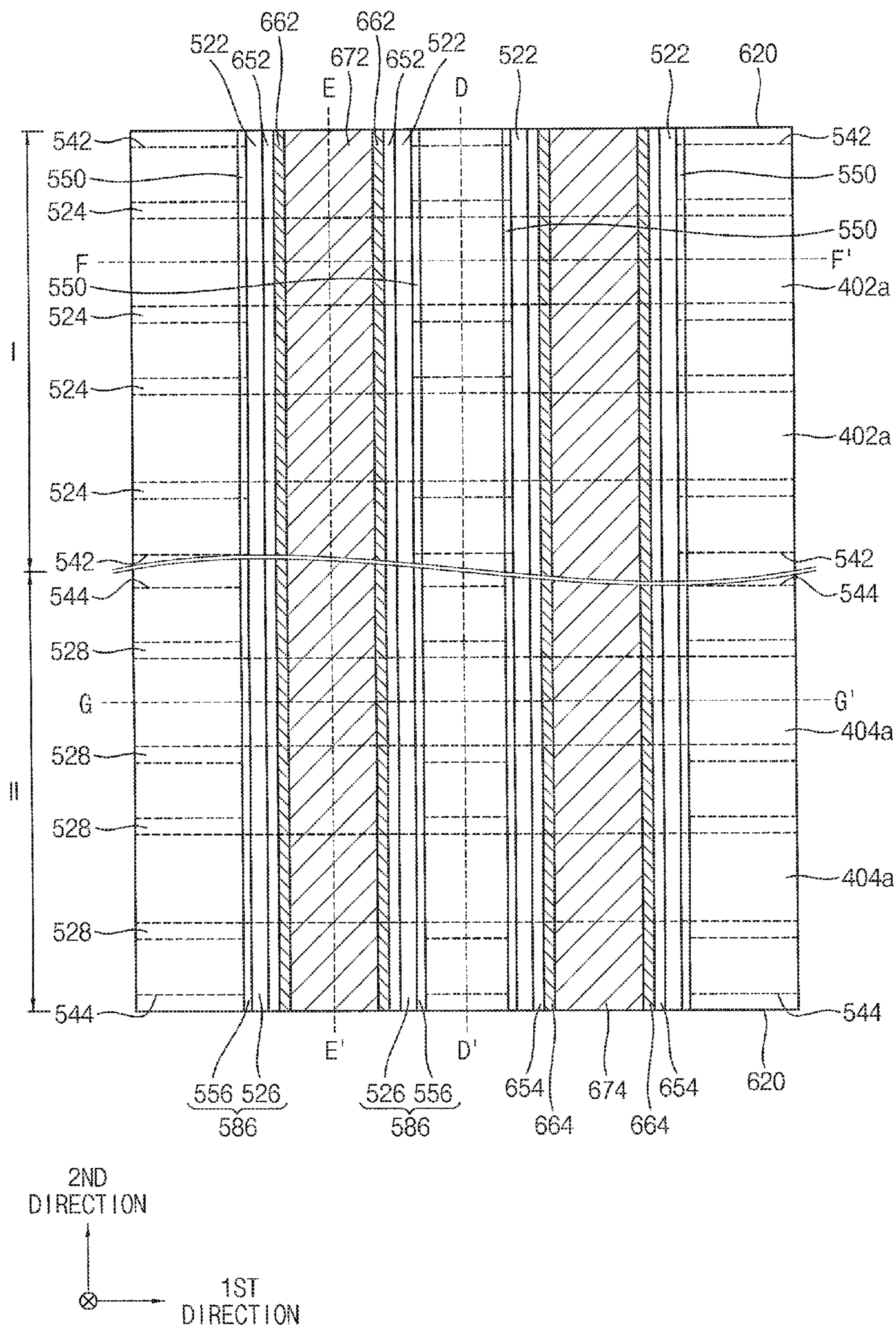




FIG. 64

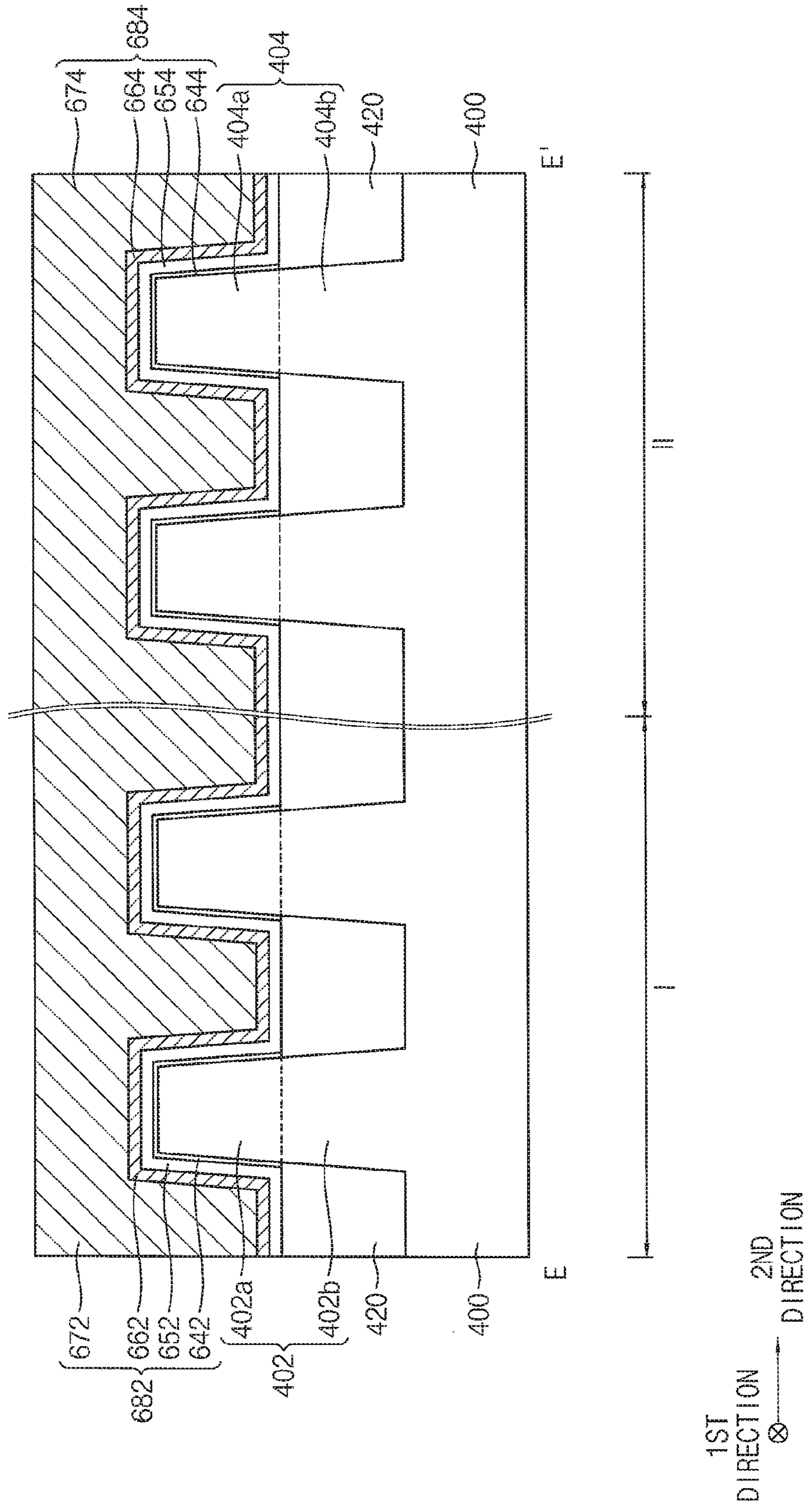


FIG. 65

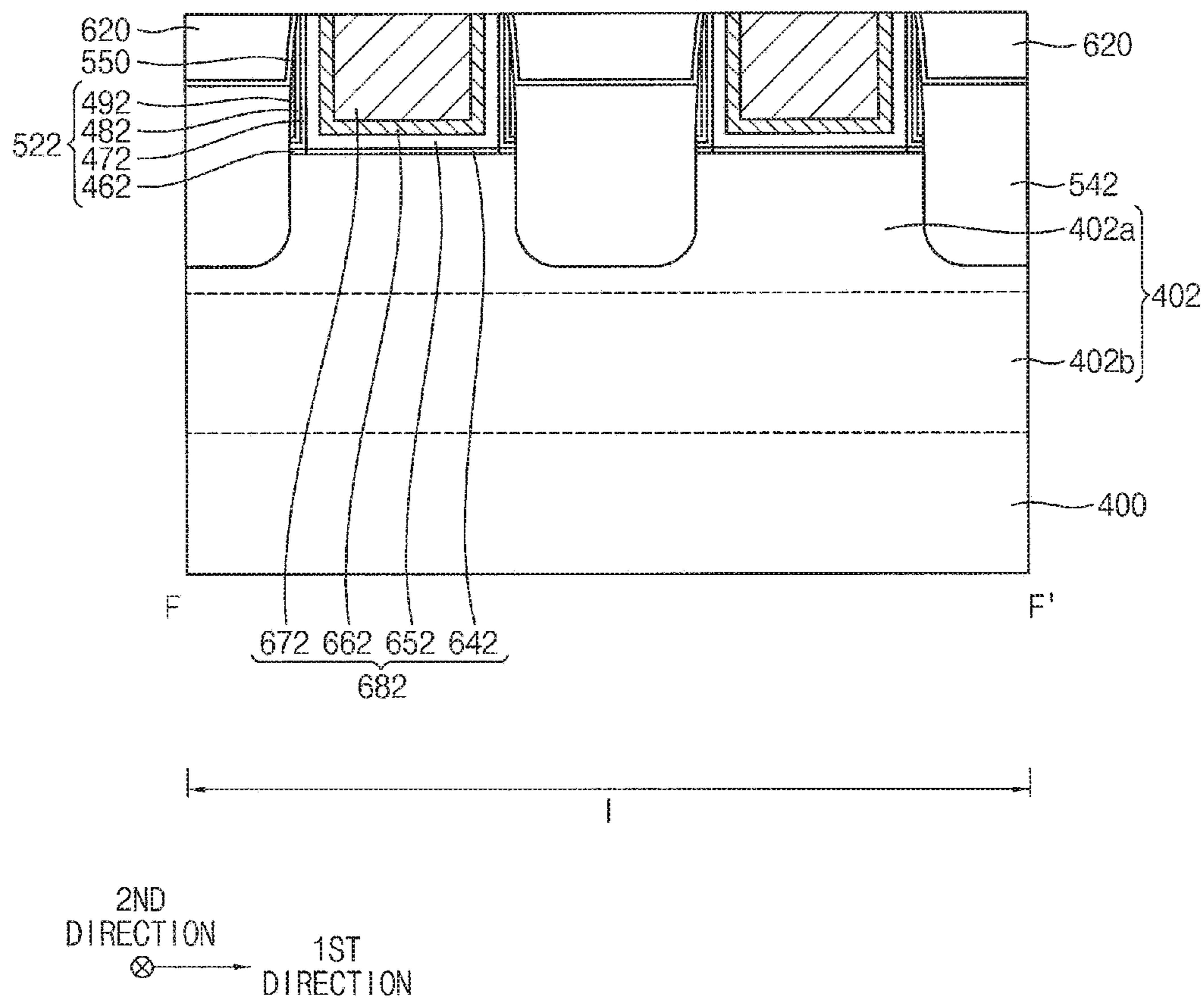


FIG. 66

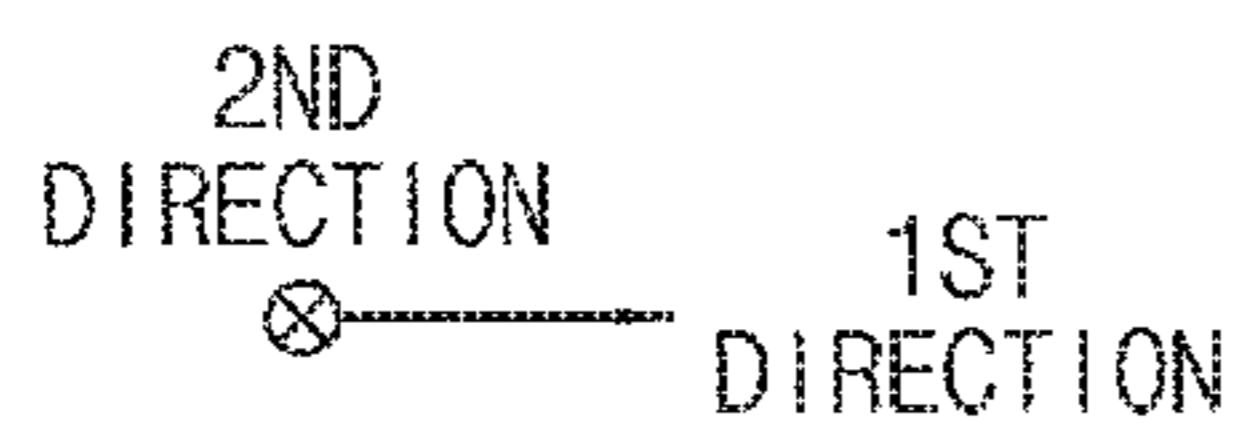
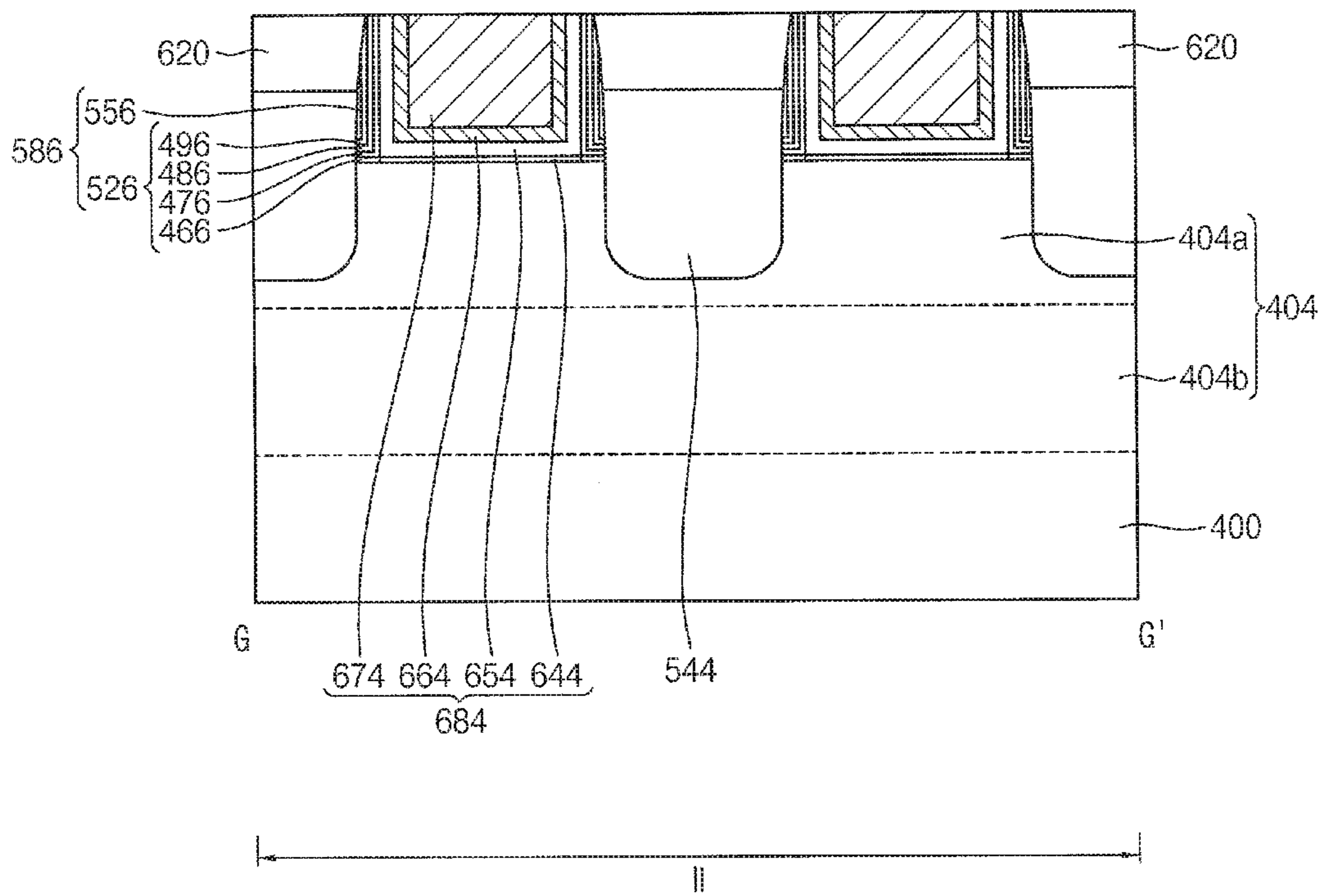




FIG. 67

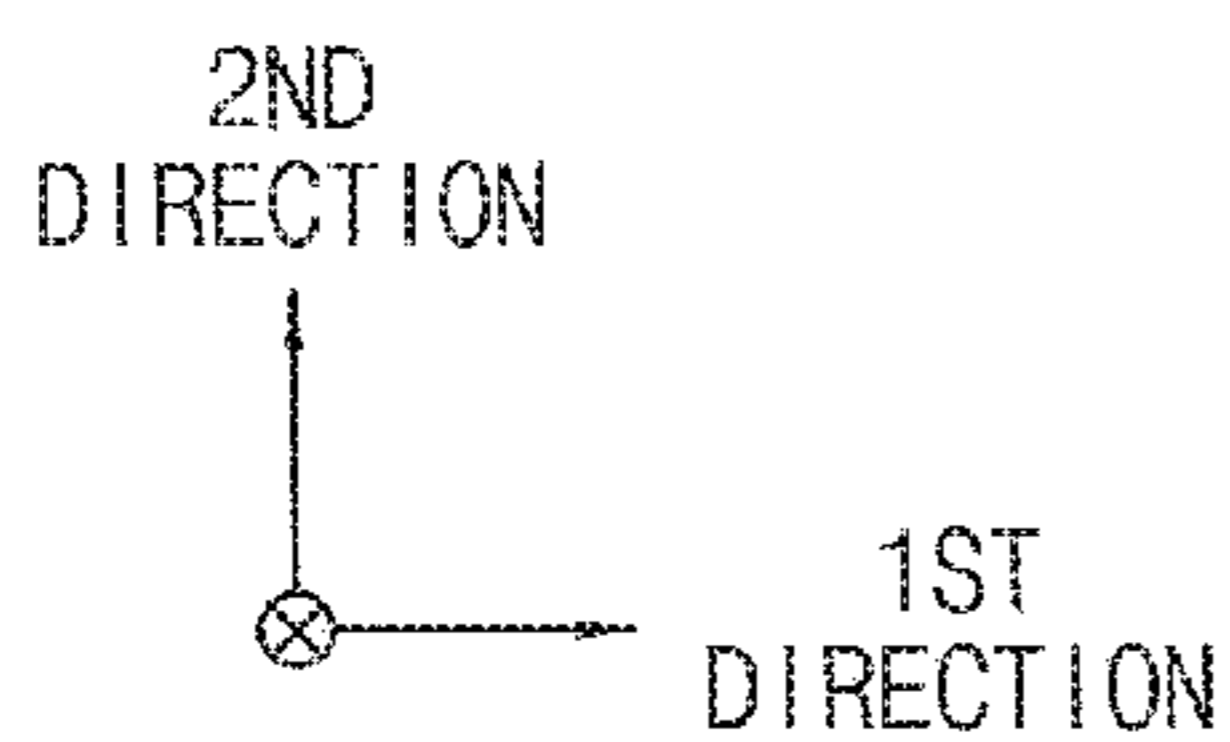
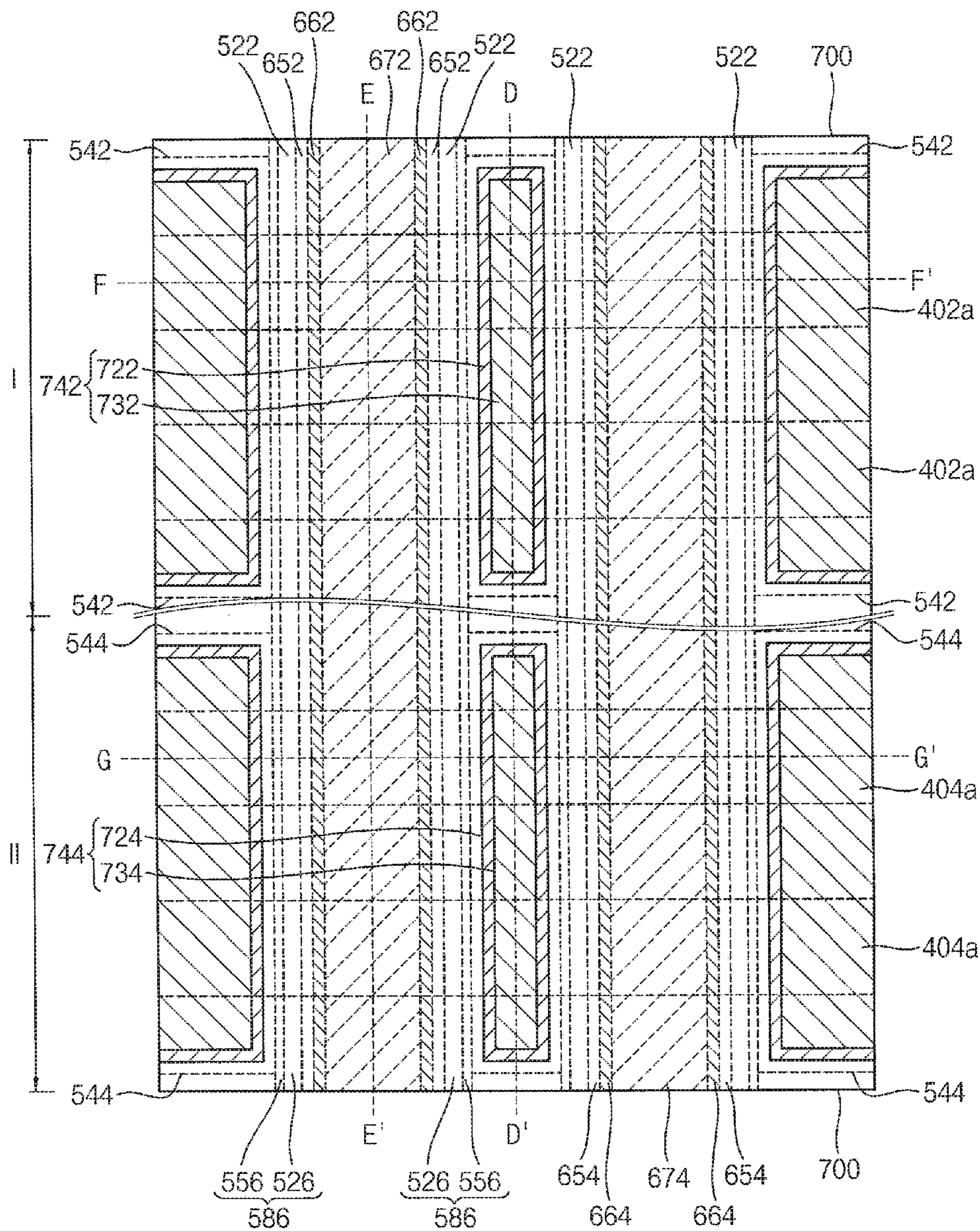


FIG. 68

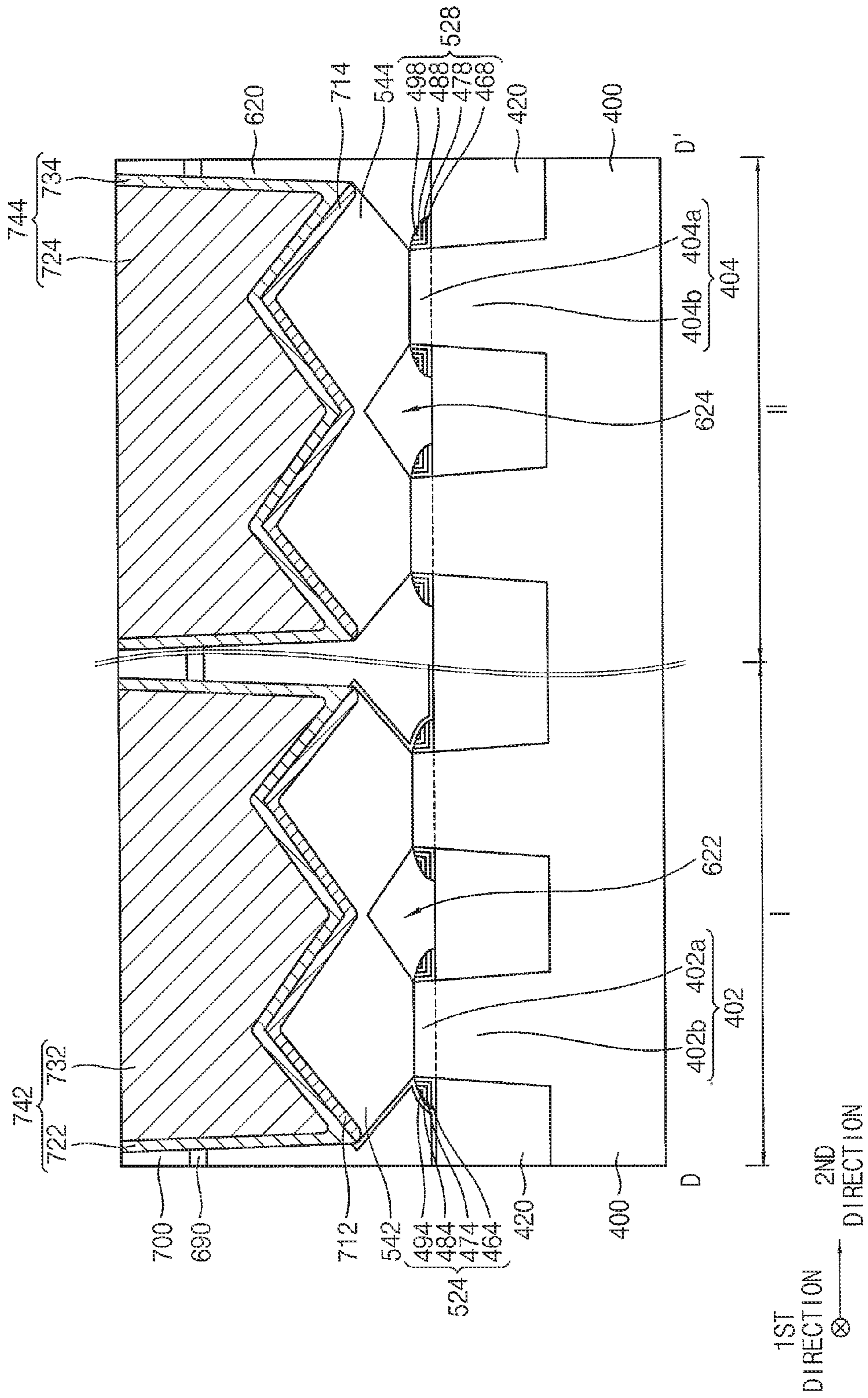




FIG. 69

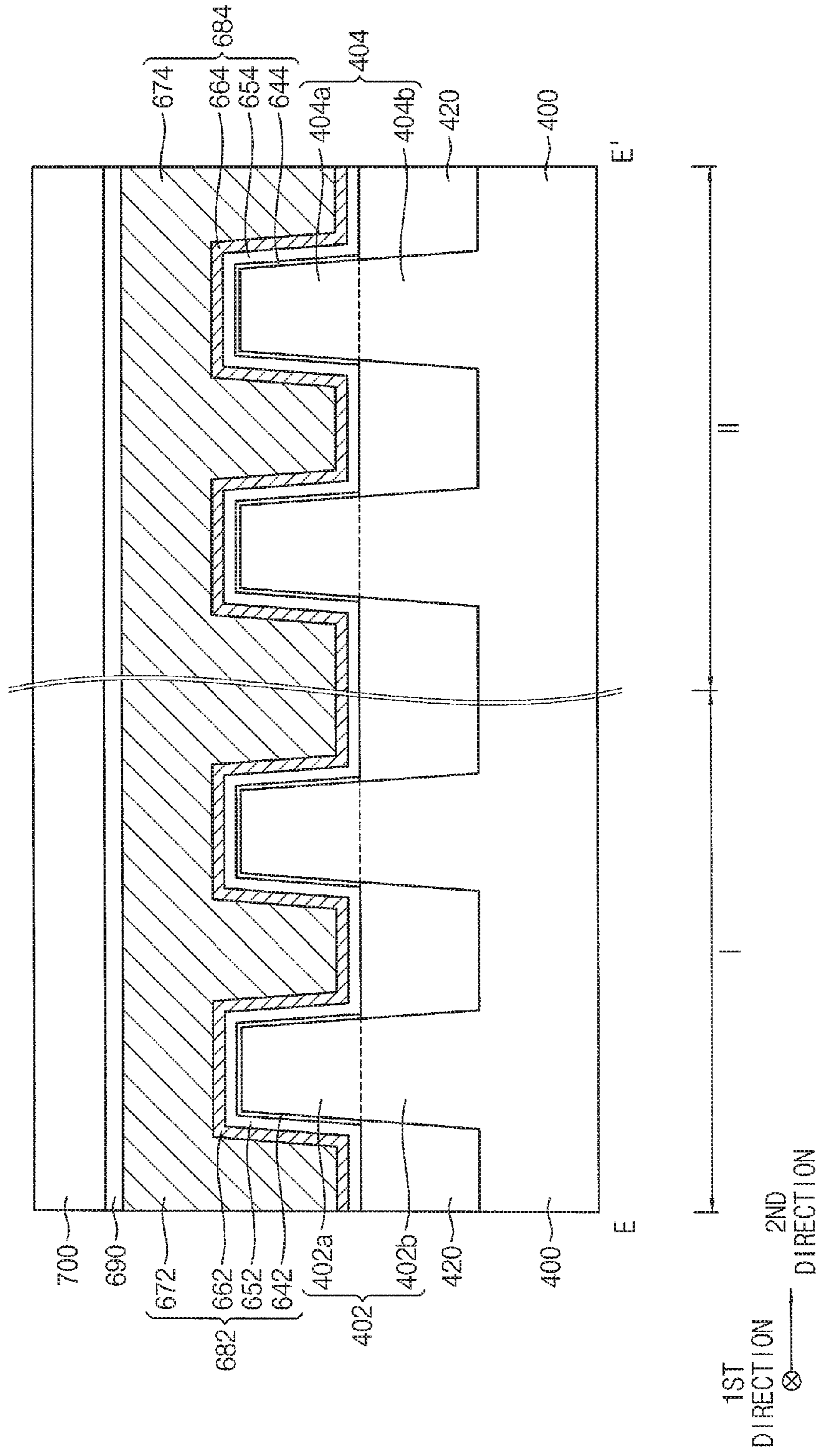




FIG. 70

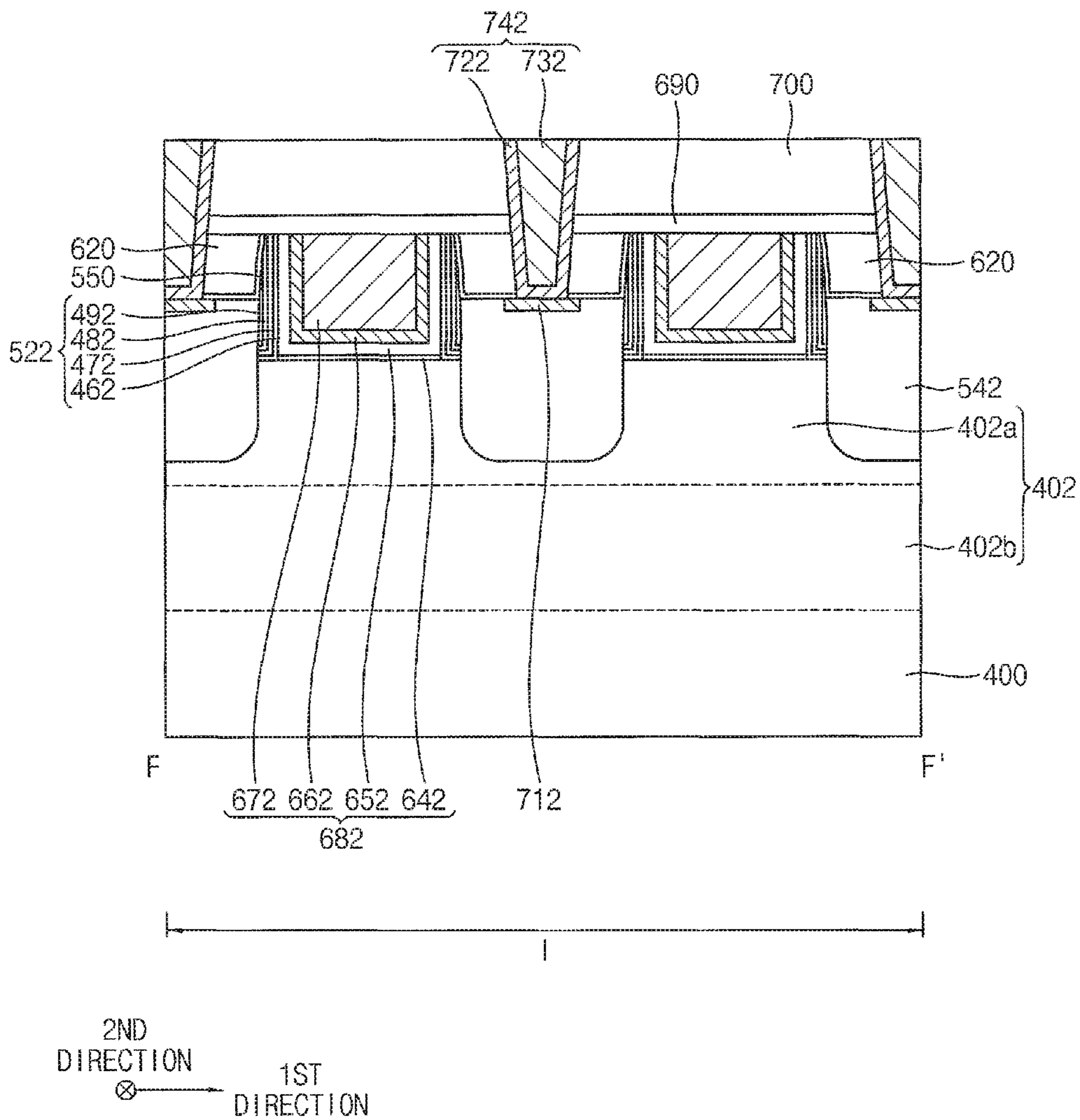
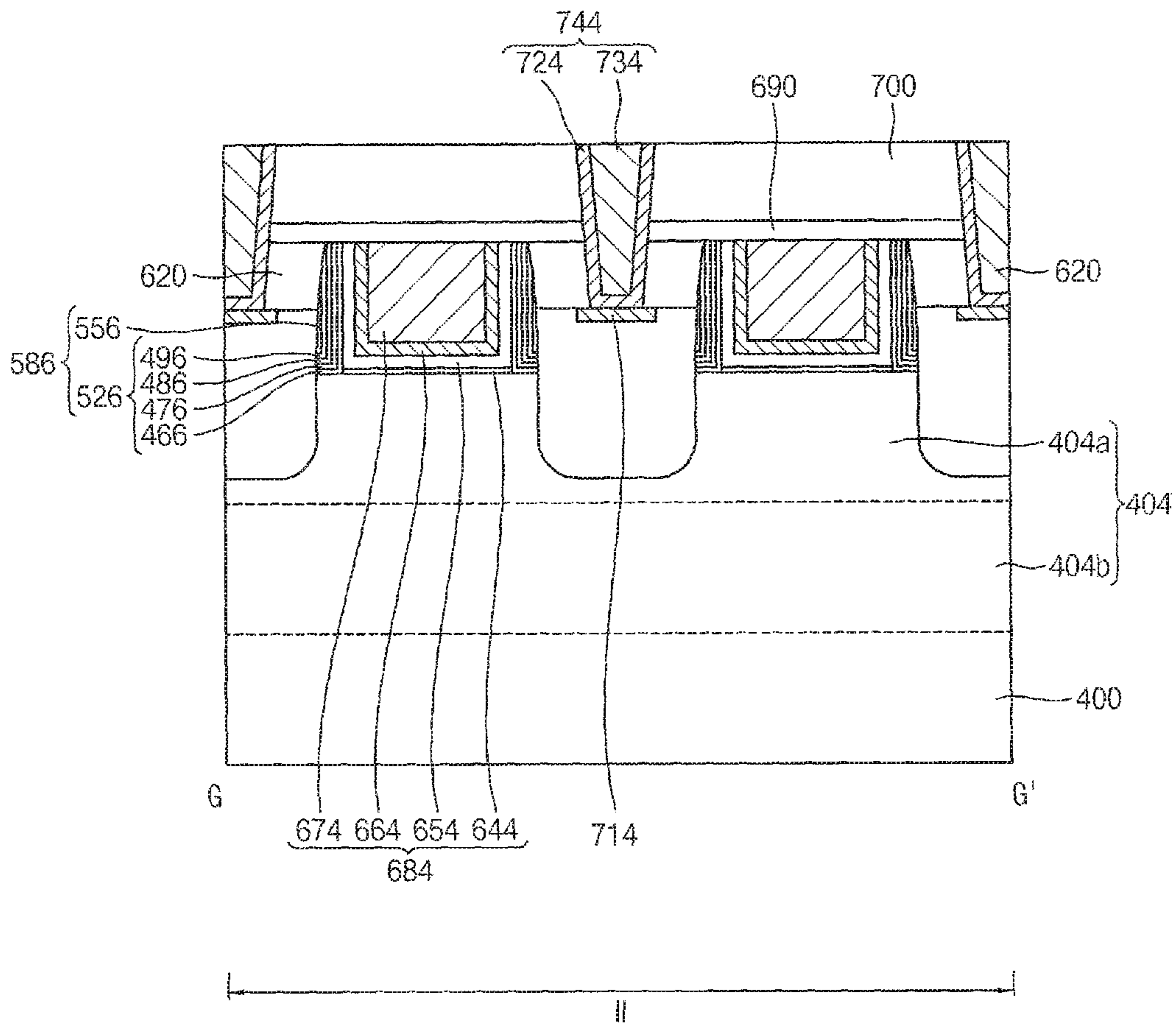


FIG. 71



2ND  
DIRECTION  
⊗ → 1ST  
DIRECTION



**1**

**SEMICONDUCTOR DEVICES AND  
METHODS OF MANUFACTURING THE  
SAME**

CROSS-REFERENCE TO RELATED  
APPLICATION

This application claims priority under 35 USC § 119 to Korean Patent Application No. 10-2016-0003213, filed on Jan. 11, 2016, in the Korean Intellectual Property Office (KIPO), the contents of which are herein incorporated by reference in their entirety.

BACKGROUND

1. Field

Example embodiments relate to semiconductor devices and methods of manufacturing the same. More particularly, example embodiments relate to semiconductor devices including spacers on sidewalls of a gate structure, and methods of manufacturing the same.

2. Description of the Related Art

When a finFET is fabricated, a spacer layer may be formed on a dummy gate, the spacer layer may be anisotropically etched to form a spacer on a sidewall of the dummy gate, an upper portion of an active fin adjacent the dummy gate may be etched using the dummy gate and the spacer as an etching mask to form a recess, and a selective epitaxial growth (SEG) process may be performed to form a source/drain layer in the recess. The dummy gate may be removed to form an opening, and a gate structure may be formed in the opening. The spacer may include a proper material for performing various etching processes and the SEG process.

SUMMARY

Example embodiments provide a semiconductor device having improved characteristics.

Example embodiments provide a method of manufacturing a semiconductor device having improved characteristics.

According to example embodiments, a semiconductor device includes an active fin on a substrate, a gate structure on the active fin, a gate spacer structure on a sidewall of the gate structure, and a source/drain layer on at least a portion of the active fin adjacent the gate spacer structure. The gate spacer structure may include a wet etch stop pattern, an oxygen-containing silicon pattern, and an outgassing prevention pattern stacked, for example sequentially stacked.

According to example embodiments, a semiconductor device includes first and second active fins on first and second regions, respectively, of a substrate, first and second gate structures on the first and second active fins, respectively, a first gate spacer structure on a sidewall of the first gate structure, a second gate spacer structure on a sidewall of the second gate structure, a first second source/drain layer on at least a portion of the first active fin adjacent the first gate spacer structure, and a second source/drain layer on at least a portion of the second active fin adjacent the second gate spacer structure. The first gate spacer structure may include a first wet etch stop pattern, a first oxygen-containing silicon pattern, and a first outgassing prevention pattern stacked, for example sequentially stacked, and the second gate spacer structure may include a second wet etch stop pattern, a second oxygen-containing silicon pattern, and a second outgassing prevention pattern stacked, for example sequentially stacked.

**2**

According to example embodiments, a method of manufacturing a semiconductor device where an isolation pattern may be formed on a substrate to define an active fin thereon. A dummy gate structure may be formed on the active fin. A gate spacer structure including a wet etch stop pattern, an oxygen-containing silicon pattern, and an outgassing reduction or prevention pattern stacked, for example sequentially stacked may be formed on a sidewall of the dummy gate structure. An upper portion of the active fin may be removed using the dummy gate structure and the gate spacer structure as an etching mask to form a recess thereon. A selective epitaxial growth (SEG) process may be performed to form a source/drain layer in the recess. The dummy gate structure may be replaced with a gate structure.

According to example embodiments, there is provided a method of manufacturing a semiconductor device. In the method, an isolation pattern may be formed on a substrate to define first and second active fins on first and second regions, respectively, of the substrate. First and second dummy gate structures may be formed on the first and second active fins, respectively. A first gate spacer structure including a first wet etch stop pattern, a first oxygen-containing silicon pattern, and a first outgassing reduction or prevention pattern stacked, for example sequentially stacked may be formed on a sidewall of the first dummy gate structure. A first selective epitaxial growth (SEG) process may be performed to form a first source/drain layer on at least a portion of the first active fin adjacent the first gate spacer structure. A second gate spacer structure including a second wet etch stop pattern, a second oxygen-containing silicon pattern, and a second outgassing reduction or prevention pattern stacked, for example sequentially stacked may be formed on a sidewall of the second dummy gate structure, the second dummy gate spacer structure. A second selective epitaxial growth (SEG) process may be performed to form a second source/drain layer on at least a portion of the second active fin adjacent the second gate spacer structure. The first and second dummy gate structures may be replaced with first and second gate structures, respectively.

In the method of manufacturing the semiconductor device, the gate spacer structure on the sidewall of the dummy gate structure may include the outgassing reduction or prevention pattern, and thus, when the source/drain layer is formed by the SEG process, e.g., carbon in the oxygen-containing silicon pattern may be prevented or impeded from outgassing therefrom, so that no defect may be generated in the source/drain layer. Additionally, the wet etch stop pattern may be formed under the oxygen-containing silicon pattern, and thus, when the wet etching process for replacing the dummy gate structure with the gate structure is performed, the gate spacer structure may not be damaged but remain.

Example embodiments relate to a semiconductor structure that includes at least one active fin on a substrate, a gate structure on the at least one active fin, a gate spacer structure on a sidewall of the gate structure, the gate spacer structure being configured to reduce outgassing of carbon, and a source/drain layer on at least a portion of the at least one active fin adjacent the gate spacer structure.

BRIEF DESCRIPTION OF THE DRAWINGS

Example embodiments will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings. FIGS. 1 to 71 represent non-limiting, example embodiments as described herein.



FIGS. 1 to 38 are plan views and cross-sectional views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments; and

FIGS. 39 to 71 are plan views and cross-sectional views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments.

#### DETAILED DESCRIPTION

These and other features and advantages are described in, or are apparent from, the following detailed description of various example embodiments.

When the terms “about” or “substantially” are used in this specification in connection with a numerical value, it is intended that the associated numerical value include a tolerance of  $\pm 10\%$  around the stated numerical value. Moreover, when reference is made to percentages in this specification, it is intended that those percentages are based on weight, i.e., weight percentages. The expression “up to” includes amounts of zero to the expressed upper limit and all values therebetween. When ranges are specified, the range includes all values therebetween such as increments of 0.1%. Moreover, when the words “generally” and “substantially” are used in connection with geometric shapes, it is intended that precision of the geometric shape is not required but that latitude for the shape is within the scope of the disclosure. Although the tubular elements of the embodiments may be cylindrical, other tubular cross-sectional forms are contemplated, such as square, rectangular, oval, triangular and others.

In the drawing figures, the dimensions of layers and regions may be exaggerated for clarity of illustration. Like reference numerals refer to like elements throughout. The same reference numbers indicate the same components throughout the specification.

FIGS. 1 to 38 are plan views and cross-sectional views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments.

Particularly, FIGS. 1, 4, 6, 9, 12, 15, 19, 22, 25, 28, 31 and 34 are plan views, and FIGS. 2-3, 5, 7-8, 10-11, 13-14, 16-18, 20-21, 23-24, 26-27, 29-30, 32-33 and 35-38 are cross-sectional views.

FIGS. 2, 3, 5, 10, 13, 16, 18, 20, 23, 32 and 35 are cross-sectional views taken along lines A-A' of corresponding plan views, respectively, FIGS. 7, 29 and 36 are cross-sectional views taken along lines B-B' of corresponding plan views, respectively, and FIGS. 8, 11, 14, 17, 21, 24, 26, 27, 30, 33, 37 and 38 are cross-sectional views taken along lines C-C' of corresponding plan views, respectively.

Referring to FIGS. 1 and 2, an upper portion of a substrate 100 may be at least partially etched to form a first recess 110.

The substrate 100 may include a semiconductor material, e.g., silicon, germanium, silicon-germanium, etc., or III-V semiconductor compounds, e.g., GaP, GaAs, GaSb, etc. In some embodiments, the substrate 100 may be a silicon-on-insulator (SOI) substrate, or a germanium-on-insulator (GOI) substrate.

As the first recess 110 is formed on the substrate 100, an active region 105 may be defined on the substrate 100. The active region 105 may protrude from an upper surface of the substrate 100, and thus may be also referred to as an active fin. A region of the substrate 100 on which the active fin 105 is not formed may be referred to as a field region.

In example embodiments, the active fin 105 may extend in a first direction substantially parallel to the upper surface of the substrate 100, and a plurality of active fins 105 may

be formed in a second direction, which may be substantially parallel to the upper surface of the substrate 100 and cross the first direction. In example embodiments, the first and second directions may cross each other at a right angle, and thus may be substantially perpendicular to each other.

In example embodiments, the active fin 105 may have a constant width from a top toward a bottom thereof, or a sidewall of the active fin 105 may have a constant slope with respect to the upper surface of the substrate 100. FIG. 2 shows that the sidewall of the active fin 105 has a constant slope with respect to the upper surface of the substrate 100.

However, referring to FIG. 3, the active fin 105 may have a width gradually increasing from a top toward a bottom thereof, and an increase ratio of the width of the sidewall may also gradually increase from the top toward the bottom thereof. Due to the characteristics of the etching process, when the first recess 110 is formed to have a large aspect ratio, the increase ratio of the width of the sidewall may gradually increase from the top toward the bottom thereof. Hereinafter, for the convenience of explanation, only the active fin 105 shown in FIG. 2 will be illustrated.

Referring to FIGS. 4 and 5, an isolation pattern 120 may be formed on the substrate 100 to fill a lower portion of the recess 110.

In example embodiments, the isolation pattern 120 may be formed by forming an isolation layer on the substrate 100 to sufficiently fill the recess 110, planarizing the isolation layer until the upper surface of the substrate 100 may be exposed, and removing an upper portion of the isolation layer to expose an upper portion of the recess 110. The isolation layer may be formed of or include an oxide, e.g., silicon oxide.

In example embodiments, the active fin 105 may include a lower active pattern 105b whose sidewall may be covered by the isolation pattern 120, and an upper active pattern 105a not covered by the isolation pattern 120 but protruding therefrom. In example embodiments, the upper active pattern 105a may have a width in the second direction that may be slightly less than a width of the lower active pattern 105b.

In example embodiments, the isolation pattern 120 may be formed to have a multi-layered structure. Particularly, the isolation pattern 120 may include first and second liners (not shown) stacked, for example sequentially stacked on an inner wall of the recess 110, and a filling insulation layer (not shown) filling a remaining portion of the recess 110 on the second liner. For example, the first liner may be formed of or include an oxide, e.g., silicon oxide, the second liner may be formed of or include a nitride, e.g., silicon nitride, or polysilicon, and the filling insulation layer may be formed of or include an oxide, e.g., silicon oxide.

Referring to FIGS. 6 to 8, a dummy gate structure may be formed on the substrate 100.

The dummy gate structure may be formed by forming, for example sequentially forming a dummy gate insulation layer, a dummy gate electrode layer and a dummy gate mask layer on the substrate 100 and the isolation pattern 120, patterning the dummy gate mask layer to form a dummy gate mask 150, and etching, for example sequentially etching the dummy gate electrode layer and the dummy gate insulation layer using the dummy gate mask 150 as an etching mask.

Thus, the dummy gate structure may include a dummy gate insulation pattern 130, a dummy gate electrode 140 and the dummy gate mask 150 stacked, for example sequentially stacked on the substrate 100.

The dummy gate insulation layer may be formed of or include an oxide, e.g., silicon oxide, the dummy gate elec-



trode layer may be formed of or include, e.g., polysilicon, and the dummy gate mask layer may be formed of or include a nitride, e.g., silicon nitride.

The dummy gate insulation layer may be formed by a chemical vapor deposition (CVD) process, an atomic layer deposition (ALD) process, etc. Alternatively, the dummy gate insulation layer may be formed by a thermal oxidation process on an upper portion of the substrate **100**, and in this case, the dummy gate insulation layer may be formed only on the upper active pattern **105a**. The dummy gate electrode layer and the dummy gate mask layer may be formed by a CVD process, an ALD process, etc.

In example embodiments, the dummy gate structure may be formed to extend in the second direction, and a plurality of dummy gate structures may be formed in the first direction.

Referring to FIGS. **9** to **11**, a spacer layer structure **210** may be formed on the active fin **105** and the isolation pattern **120** to cover the dummy gate structure.

In example embodiments, the spacer layer structure **210** may include a diffusion reduction or prevention layer **160**, a wet etch stop layer **170**, an oxygen-containing silicon layer **180**, an outgassing reduction or prevention layer **190** and an offset layer **200** stacked, for example sequentially stacked.

The diffusion reduction or prevention layer **160** may reduce or prevent components of the wet etch stop layer **170** from diffusing into the active fin **105**. For example, when the wet etch stop layer **170** includes silicon carbonitride, carbon in the wet etch stop layer **170** may be prevented by the diffusion reduction or prevention layer **160** from diffusing into the active fin **105**. The diffusion reduction or prevention layer **160** may be formed of or include, e.g., silicon nitride.

The wet etch stop layer **170** may not be removed by a wet etching process subsequently performed. The wet etch stop layer **170** may be formed of or include, e.g., silicon carbonitride.

The oxygen-containing silicon layer **180** may be formed of or include oxygen, thereby having a dielectric constant at least lower than silicon nitride. The oxygen-containing silicon layer **180** may be formed of or include, e.g., silicon oxycarbonitride, silicon dioxide and/or silicon oxynitride, etc.

The outgassing reduction or prevention layer **190** may reduce or prevent components of the oxygen-containing silicon layer **180**, e.g., carbon from outgassing in subsequent processes. The outgassing reduction or prevention layer **190** may be formed of or include, e.g., silicon nitride.

The offset layer **200** may compensate a thickness of a preliminary gate spacer structure **212** (refer to FIGS. **12** to **14**), which may be formed by anisotropically etching the spacer layer structure **210** subsequently, so that the preliminary gate spacer structure **212** may have a desired thickness. The offset layer **200** may be formed of or include, e.g., silicon dioxide.

Referring to FIGS. **12** to **14**, the spacer layer structure **210** may be anisotropically etched to form the preliminary gate spacer structure **212** on each or at least one of opposite sidewalls of the dummy gate structure in the first direction. A preliminary fin spacer structure **214** may be formed on each or at least one of opposite sidewalls of the upper active pattern **105a** in the second direction.

The preliminary gate spacer structure **212** may include a first diffusion reduction or prevention pattern **162**, a first wet etch stop pattern **172**, a first oxygen-containing silicon pattern **182**, a first outgassing reduction or prevention pattern **192** and a first offset pattern **202** stacked, for example sequentially stacked. The preliminary fin spacer structure

**214** may include a second diffusion reduction or prevention pattern **162**, a second wet etch stop pattern **174**, a second oxygen-containing silicon pattern **184**, a second outgassing reduction or prevention pattern **194** and a second offset pattern **204** stacked, for example sequentially stacked.

Referring to FIGS. **15** to **17**, an upper portion of the active fin **105** adjacent the preliminary gate spacer structure **212** may be etched to form a second recess **230**.

Particularly, the upper portion of the active fin **105** may be removed using the dummy gate structure and the preliminary gate spacer structure **212** on a sidewall thereof as an etching mask to form the second recess **230**. In example embodiments, when the second recess **230** is formed, the first offset pattern **202** including silicon dioxide, which may be easily removed in a dry etching process, may be removed, however, the first outgassing reduction or prevention pattern **192** including silicon nitride, which may not be easily removed in a dry etching process, may not be removed but remain.

Thus, the preliminary gate spacer structure **212** may be transformed into a gate spacer structure **222** including the first diffusion reduction or prevention pattern **162**, the first wet etch stop pattern **172**, the first oxygen-containing silicon pattern **182** and the first outgassing reduction or prevention pattern **192** stacked, for example sequentially stacked.

When the second recess **230** is formed, the preliminary fin spacer structure **214** adjacent the active fin **105** may be mostly removed, and only at least a portion of the preliminary fin spacer structure **214** may remain and may be referred to as a fin spacer structure **224**. The preliminary fin spacer structure **214** may have the second offset pattern **204** including silicon dioxide that may be easily removed in a dry etching process, and thus may be easily removed.

The fin spacer structure **224** may include the second diffusion reduction or prevention pattern **164**, the second wet etch stop pattern **174**, the second oxygen-containing silicon pattern **184** and the second outgassing reduction or prevention pattern **194** stacked, for example sequentially stacked. In example embodiments, a height of a top surface of the remaining fin spacer structure **224** may be equal to or lower than a height of the active fin **105** under the second recess **230**.

FIGS. **15** to **17** show that only a portion of the upper active pattern **105a** is etched to form the second recess **230**, so that a bottom of the second recess **230** is higher than a top surface of the lower active pattern **105b**, however, the inventive concepts may not be limited thereto.

For example, referring to FIG. **18**, when the second recess **230** is formed, the upper active pattern **105a** may be removed so that the bottom of the second recess **230** may be substantially coplanar with the top surface of the lower active pattern **105b**. In this case, the preliminary fin spacer structure **214** may be completely removed so that the fin spacer structure **224** may not remain.

Alternatively, when the second recess **230** is formed, not only the upper active pattern **105a** but also a portion of the lower active pattern **105b** may be etched, and thus the bottom of the second recess **230** may be lower than a top surface of the lower active pattern **105b** on which the second recess **230** is not formed.

In example embodiments, the etching process for forming the second recess **230** and the etching process for forming the preliminary gate spacer structure **212** and the preliminary fin spacer structure **214** may be performed in-situ.

Referring to FIGS. **19** to **21**, a source/drain layer **240** may be formed in the second recess **230**.



In example embodiments, the source/drain layer **240** may be formed by a selective epitaxial growth (SEG) process using an upper surface of the active fin **105** exposed by the second recess **230** as a seed.

In example embodiments, the SEG process may be formed by providing a silicon source gas, a germanium source gas, an etching gas and a carrier gas. The SEG process may be performed using e.g., silane ( $\text{SiH}_4$ ) gas, disilane ( $\text{Si}_2\text{H}_6$ ) gas, dichlorosilane (DCS) ( $\text{SiH}_2\text{Cl}_2$ ) gas, etc., serving as the silicon source gas, e.g., germane ( $\text{GeH}_4$ ) gas serving as the germanium source gas, e.g., hydrogen chloride (HCl) gas serving as the etching gas, and e.g., hydrogen ( $\text{H}_2$ ) gas serving as the carrier gas. Thus, a single crystalline silicon-germanium layer may be formed to serve as the source/drain layer **240**. Additionally, a p-type impurity source gas, e.g., diborane ( $\text{B}_2\text{H}_6$ ) gas may be also used to form a single crystalline silicon-germanium layer doped with p-type impurities serving as the source/drain layer **240**. Thus, the source/drain layer **240** may serve as a source/drain region of a positive-channel metal oxide semiconductor (PMOS) transistor.

During the SEG process, when the first oxygen-containing silicon pattern **182** of the gate spacer structure **222** includes, e.g., silicon carbonitride, carbon of the first oxygen-containing silicon pattern **182** may be outgassed, and thus facet may be formed on the source/drain layer **240** to generate defects therein. However, in example embodiments, the first outgassing reduction or prevention pattern **192** may be formed on the first oxygen-containing silicon pattern **182** of the gate spacer structure **222**, and thus, when the SEG process is performed, carbon may be prevented from outgassing from the first oxygen-containing silicon pattern **182**.

The remaining fin spacer structure **224** may also have the second outgassing reduction or prevention pattern **194**, and thus carbon may be prevented from outgassing from the second oxygen-containing silicon pattern **184**.

The source/drain layer **240** may grow not only in a vertical direction but also in a horizontal direction to fill the second recess **230**, and may contact a sidewall of the gate spacer structure **222**. For example, when the substrate **100** is a (100) silicon substrate and the active fin **105** has a  $\langle 110 \rangle$  crystal direction, the source/drain layer **240** may have a lowest growth rate along the  $\langle 110 \rangle$  crystal direction, and thus the source/drain layer **240** may have a  $\{111\}$  crystal plane.

In example embodiments, the source/drain layer **240** may have a cross-section taken along the second direction, and the cross-section of the source/drain layer **240** may have a shape similar to or the same as a pentagon. In the shape, each or at least one of four sides except for one side contacting the upper surface of the active fin **105** may have an angle of about 54.7 degrees with respect to an upper surface of the substrate **100** or an upper surface of the isolation pattern **120**.

In example embodiments, when the active fins **105** disposed in the second direction are close to each other, the source/drain layers **240** growing on the respective active fins **105** may be merged with each other. FIGS. **19** to **21** show that two source/drain layers **240** grown on neighboring two active fins **105** are merged with each other, however, the inventive concepts may not be limited thereto. Thus, more than two source/drain layers **240** may be merged with each other.

Up to now, the source/drain layer **240** serving as the source/drain region of the PMOS transistor have been illustrated, however, the inventive concepts may not be limited

thereto, and the source/drain layer **240** may also serve as a source/drain region of a negative-channel metal oxide semiconductor (NMOS) transistor.

Particularly, the SEG process may be formed using a silicon source gas, a carbon source gas, an etching gas and a carrier gas, and thus a single crystalline silicon carbide layer may be formed as the source/drain layer **240**. In the SEG process, e.g., silane ( $\text{SiH}_4$ ) gas, disilane ( $\text{Si}_2\text{H}_6$ ) gas, dichlorosilane ( $\text{SiH}_2\text{Cl}_2$ ) gas, etc., may be used as the silicon source gas, e.g., monomethylsilane ( $\text{SiH}_3\text{CH}_3$ ) gas may be used as the carbon source gas, e.g., hydrogen chloride (HCl) gas may be used as the etching gas, and e.g., hydrogen ( $\text{H}_2$ ) gas may be used as the carrier gas. Additionally, an n-type impurity source gas, e.g., phosphine ( $\text{PH}_3$ ) gas may be also used to form a single crystalline silicon carbide layer doped with n-type impurities.

Alternatively, the SEG process may be performed using a silicon source gas, an etching gas and a carrier gas, and thus a single crystalline silicon layer may be formed as the source/drain layer **240**. In the SEG process, an n-type impurity source gas, e.g., phosphine ( $\text{PH}_3$ ) gas may be also used to form a single crystalline silicon layer doped with n-type impurities.

Referring to FIGS. **22** to **24**, an insulation layer **250** may be formed on the active fin **105** and the isolation pattern **120** to cover the dummy gate structure, the gate spacer structure **222**, the fin spacer structure **224** and the second source/drain layer **240** to a sufficient height, and may be planarized until an upper surface of the dummy gate electrode **140** of the dummy gate structure may be exposed.

In the planarization process, the dummy gate mask **150** may be removed, and an upper portion of the gate spacer structure **222** may be at least partially removed.

A space between the merged source/drain layers **240** and the isolation pattern **120** may not be filled with the insulation layer **250**, and thus an air gap **255** may be formed.

The insulation layer **250** may be formed of or include silicon oxide, e.g., tonen silazene (TOSZ). The planarization process may be performed by a chemical mechanical polishing (CMP) process and/or an etch back process.

Referring to FIGS. **25** to **27**, the exposed dummy gate electrode **140** and the dummy gate insulation pattern **130** thereunder may be removed to form an opening **260** exposing an inner sidewall of the gate spacer structure **222** and an upper surface of the active fin **105**.

In example embodiments, the dummy gate electrode **140** and the dummy gate insulation pattern **130** may be removed by a dry etching process or a wet etching process.

The wet etching process may be performed using, e.g., hydrofluoric acid (HF), and the first diffusion reduction or prevention pattern **162** may be at least partially removed to expose the first wet etch stop pattern **172**. The first wet etch stop pattern **172** may not be easily removed by the wet etching process, and thus at least a portion of the first wet etch stop pattern **172** may remain. Accordingly, a remaining portion of the gate spacer structure **222** may not be damaged.

A portion of the first diffusion reduction or prevention pattern **162** on a sidewall of the first wet etch stop pattern **172** may be mostly removed, however, at least a portion of the first diffusion reduction or prevention pattern **162** on the upper surface of the active fin **105** may not completely removed but at least partially remain. Thus, the source/drain layer **240** adjacent the first diffusion reduction or prevention pattern **162** may not be exposed by the opening **260**.

FIG. **26** shows that the first diffusion reduction or prevention pattern **162** is at least partially removed so that a sidewall of the remaining first diffusion reduction or pre-



vention pattern **162** may be aligned with an extension plane of the sidewall of the first wet etch stop pattern **172**, and thus an upper surface of the first diffusion reduction or prevention pattern **162** may have an area substantially equal to a bottom of the first wet etch stop pattern **172**.

However, the inventive concepts may not be limited thereto.

For example, referring to FIG. **27**, the first diffusion reduction or prevention pattern **162** may be at least partially removed so that a sidewall of the remaining first diffusion reduction or prevention pattern **162** may not be aligned with the extension plane of the sidewall of the first wet etch stop pattern **172**, and an upper surface of the first diffusion reduction or prevention pattern **162** may have an area less than the bottom of the first wet etch stop pattern **172**.

Referring to FIGS. **28** to **30**, a gate structure **310** may be formed to fill the opening **260**.

Particularly, after performing a thermal oxidation process on the upper surface of the active fin **105** exposed by the opening **260** to form an interface pattern **270**, a gate insulation layer and a work function control layer may be formed, for example sequentially formed on the interface pattern **270**, the isolation pattern **120**, the gate spacer structure **222**, and the insulation layer **250**, and a gate electrode layer may be formed on the work function control layer to sufficiently fill a remaining portion of the opening **260**.

The gate insulation layer may be formed of a metal oxide having a high dielectric constant, e.g., hafnium oxide, tantalum oxide, zirconium oxide, or the like, by a CVD process or an ALD process. The work function control layer may be formed of a metal nitride or a metal alloy, e.g., titanium nitride, titanium aluminum, titanium aluminum nitride, tantalum nitride, tantalum aluminum nitride, etc., and the gate electrode layer may be formed of a material having a low resistance, e.g., a metal such as aluminum, copper, tantalum, etc., or a metal nitride thereof. The work function control layer and the gate electrode layer may be formed by an ALD process, a physical vapor deposition (PVD) process, or the like. In an example embodiment, a heat treatment process, e.g., a rapid thermal annealing (RTA) process, a spike rapid thermal annealing (spike RTA) process, a flash rapid thermal annealing (flash RTA) process or a laser annealing process may be further performed.

The interface pattern **270** may be formed instead of the thermal oxidation process, by a CVD process, an ALD process, or the like, similarly to the gate insulation layer or the gate electrode layer. In this case, the interface pattern **270** may be formed not only on the upper surface of the active fin **105** but also on the upper surface of the isolation pattern **120** and the inner sidewall of the gate spacer structure **222**.

The gate electrode layer, the work function control layer, and the gate insulation layer may be planarized until an upper surface of the insulation layer **250** may be exposed to form a gate insulation pattern **280** and a work function control pattern **290** stacked, for example sequentially stacked on the interface pattern **270**, the isolation pattern **120**, and the inner sidewall of the gate spacer structure **222**, and a gate electrode **300** filling the remaining portion of the opening **260** on the work function control pattern **290**.

Accordingly, a bottom and a sidewall of the gate electrode **300** may be covered by the work function control pattern **290**. In example embodiments, the planarization process may be performed by a CMP process and/or an etch back process.

The interface pattern **270**, the gate insulation pattern **280**, the work function control pattern **290** and the gate electrode **300** stacked, for example sequentially stacked may form the

gate structure **310**, and the gate structure **310** together with the source/drain layer **240** may form a PMOS transistor or an NMOS transistor according to the conductivity type of the source/drain layer **240**.

Referring to FIGS. **31** to **33**, a capping layer **320** and an insulating interlayer **330** may be formed, for example sequentially formed on the insulation layer **250**, the gate structure **310**, and the gate spacer structure **222**, and a contact hole **340** may be formed through the insulation layer **250**, the capping layer **320** and the insulating interlayer **330** to expose an upper surface of the source/drain layer **240**.

The capping layer **320** may be formed of a nitride, e.g., silicon nitride, silicon oxynitride, silicon carbonitride, silicon oxycarbonitride, etc., and the insulating interlayer **330** may be formed of silicon oxide, e.g., tetra ethyl ortho silicate (TEOS).

In example embodiments, the contact hole **340** may be formed to be self-aligned with the gate spacer structure **222**, and thus may expose an entire portion of the upper surface of the source/drain layer **240** in the first direction. However, the inventive concepts may not be limited thereto, and the contact hole **340** may not be self-aligned with the gate spacer structure **222**, but may expose only a portion of the upper surface of the source/drain layer **240** in the first direction.

Referring to FIGS. **34** to **37**, after forming a first metal layer on the exposed upper surface of the source/drain layer **240**, a sidewall of the contact hole **340**, and the upper surface of the insulating interlayer **330**, a heat treatment process may be performed thereon to form a metal silicide pattern **350** on the source/drain layer **240**. An unreacted portion of the first metal layer may be removed.

The first metal layer may be formed of a metal, e.g., titanium, cobalt, nickel, etc.

A barrier layer may be formed on the metal silicide pattern **350**, the sidewall of the contact hole **340** and the upper surface of the insulating interlayer **330**, a second metal layer may be formed on the barrier layer to fill the contact hole **340**, and the second metal layer and the barrier layer may be planarized until the upper surface of the insulating interlayer **330** may be exposed.

Thus, a contact plug **380** may be formed on the metal silicide pattern **350** to fill the contact hole **340**.

The barrier layer may be formed of a metal nitride, e.g., titanium nitride, tantalum nitride, tungsten nitride, etc., and the second metal layer may be formed of a metal, e.g., tungsten, copper, etc.

The contact plug **380** may include a metal pattern **370** and a barrier pattern **360** covering a bottom and a sidewall thereof.

A wiring (not shown) and a via (not shown) may be further formed to be electrically connected to the contact plug **380** to complete the semiconductor device.

FIG. **38** shows that the semiconductor device includes the first diffusion reduction or prevention pattern **162** of which an upper surface may have an area less than the bottom of the first wet etch stop pattern **172**, as shown in FIG. **27**.

As illustrated above, the gate spacer structure **222** may include the first outgassing reduction or prevention pattern **192** on the sidewall of the dummy gate structure, and thus, when the source/drain layer **240** is formed by the SEG process, e.g., carbon in the first oxygen-containing silicon pattern **182** may be prevented from outgassing therefrom, so that no defect may be generated in the source/drain layer **240**. Additionally, the first wet etch stop pattern **172** may be formed under the first oxygen-containing silicon pattern **182**, and thus, when the wet etching process for replacing the



dummy gate structure with the gate structure **310** is performed, the gate spacer structure **222** may not be damaged but remain.

When the first wet etch stop pattern **172** includes, e.g., silicon carbonitride, carbon in the first wet etch stop pattern **172** may be prevented by the first diffusion reduction or prevention pattern **162** under the first wet etch stop pattern **172** from diffusing into the active fin **105**. Additionally, even if the first diffusion reduction or prevention pattern **162** is easily removed in the wet etching process so that at least a portion of the first diffusion reduction or prevention pattern **162** on the sidewall of the first wet etch stop pattern **172** is completely removed, at least a portion of the first diffusion reduction or prevention pattern **162** on the active fin **105** may not be completely removed, and thus the opening **260** formed in the wet etching process may not expose the source/drain layer **240**.

Each or at least one of the first wet etch stop pattern **172** and the first oxygen-containing silicon pattern **182** of the gate spacer structure **222** may have a cross-section taken along the first direction, which may have an L-like shape, and a sidewall and a bottom of the first outgassing reduction or prevention pattern **192** may be covered by the first oxygen-containing silicon pattern **182**.

FIGS. **39** to **71** are plan views and cross-sectional views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments. Particularly, FIGS. **39**, **41**, **44**, **48**, **51**, **55**, **59**, **63** and **67** are plan views, and FIGS. **40**, **42-43**, **45-47**, **49-50**, **52-54**, **56-58**, **60-62**, **64-66** and **68-71** are cross-sectional views.

FIGS. **40**, **45**, **49**, **52**, **56**, **60** and **68** are cross-sectional views taken along lines D-D' of corresponding plan views, respectively, FIGS. **42**, **64** and **69** are cross-sectional views taken along lines E-E' of corresponding plan views, respectively, FIGS. **43**, **46**, **50**, **53**, **57**, **61**, **65** and **70** are cross-sectional views taken along lines F-F' of corresponding plan views, respectively, and FIGS. **47**, **54**, **58**, **62**, **66** and **71** are cross-sectional views taken along lines G-G' of corresponding plan views.

This method is an application to a complementary metal oxide semiconductor (CMOS) transistor of the method illustrated with reference to FIGS. **1** to **38**. Thus, the method may include processes substantially the same as or similar to those illustrated with reference to FIGS. **1** to **38**, and detailed descriptions thereon are omitted herein.

Referring to FIGS. **39** and **40**, processes substantially the same as or similar to those illustrated with reference to FIGS. **1** to **5** may be performed.

Thus, upper portions of a substrate **400** may be at least partially etched to form first and second recesses **412** and **414**.

The substrate **400** may include first and second regions I and II. In example embodiments, the first region I may serve as a PMOS region, and the second region II may serve as an NMOS region.

As the first and second recesses **412** and **414** are formed on the substrate **400**, first and second active regions **402** and **404** may be defined on the first and second regions I and II, respectively, of the substrate **400**. The first and second active regions **402** and **404** may be also referred to as first and second active fins, respectively. A region of the substrate **400** on which no active fin is formed may be referred to as a field region.

In example embodiments, each or at least one of the first and second active regions **402** and **404** may extend in a first direction substantially parallel to an upper surface of the substrate **400**, and a plurality of first active fins **402** and a

plurality of second active fins **404** may be formed in a second direction, which may be substantially parallel to the upper surface of the substrate **400** and cross the first direction. In example embodiments, the first and second directions may cross each other at a right angle, and thus may be substantially perpendicular to each other.

An isolation pattern **420** may be formed on the substrate **400** to fill lower portions of the first and second recesses **412** and **414**.

The first active fin **402** may include a first lower active pattern **402b** whose sidewall may be covered by the isolation pattern **420**, and a first upper active pattern **402a** not covered by the isolation pattern **420** but protruding therefrom. The second active fin **404** may include a second lower active pattern **404b** whose sidewall may be covered by the isolation pattern **420**, and a second upper active pattern **404a** not covered by the isolation pattern **420** but protruding therefrom.

Referring to FIGS. **41** to **43**, processes substantially the same as or similar to those illustrated with reference to FIGS. **6** to **8** may be performed to form first and second dummy gate structures on the first and second regions I and II, respectively, of the substrate **400**.

The first dummy gate structure may include a first dummy gate insulation pattern **432**, a first dummy gate electrode **442** and the first dummy gate mask **452** stacked, for example sequentially stacked on the first region I of the substrate **400**, and the second dummy gate structure may include a second dummy gate insulation pattern **434**, a second dummy gate electrode **444** and the second dummy gate mask **454** stacked, for example sequentially stacked on the second region II of the substrate **400**.

Referring to FIGS. **44** to **47**, processes substantially the same as or similar to those illustrated with reference to FIGS. **9** to **11** may be performed to form a preliminary spacer layer structure **510** on the first and second active fins **402** and **404** and the isolation pattern **420** to cover the first and second dummy gate structures.

In example embodiments, the preliminary spacer layer structure **510** may include a diffusion reduction or prevention layer **460**, a wet etch stop layer **470**, an oxygen-containing silicon layer **480**, an outgassing reduction or prevention layer **490** and a first offset layer **500** stacked, for example sequentially stacked.

The diffusion reduction or prevention layer **460** may be formed of, e.g., silicon nitride, the wet etch stop layer **470** may be formed of, e.g., silicon carbonitride, the oxygen-containing silicon layer **480** may be formed of e.g., silicon oxycarbonitride, silicon dioxide and/or silicon oxynitride, etc., the outgassing reduction or prevention layer **490** may be formed of, e.g., silicon nitride, and the offset layer **500** may be formed of, e.g., silicon dioxide.

A first photoresist pattern **10** may be formed to cover the second region II of the substrate **400**, and processes substantially the same as or similar to those illustrated with reference to FIGS. **12** to **14** may be performed to anisotropically etch the preliminary spacer layer structure **510**.

Thus, a first preliminary gate spacer structure **512** may be formed on each or at least one of opposite sidewalls of the first dummy gate structure in the first direction on the first region I of the substrate **400**, and a first preliminary fin spacer structure **514** may be formed on each or at least one of opposite sidewalls of the first upper active pattern **402a** in the second direction on the first region I of the substrate **400**.

The first preliminary gate spacer structure **512** may include a first diffusion reduction or prevention pattern **462**, a first wet etch stop pattern **472**, a first oxygen-containing



silicon pattern **482**, a first outgassing reduction or prevention pattern **492** and a first offset pattern **502** stacked, for example sequentially stacked, and the first preliminary fin spacer structure **514** may include a second diffusion reduction or prevention pattern **464**, a second wet etch stop pattern **474**, a second oxygen-containing silicon pattern **484**, a second outgassing reduction or prevention pattern **494** and a second offset pattern **504** stacked, for example sequentially stacked.

A portion of the preliminary spacer layer structure **510** on the second region II of the substrate **400** may remain.

Referring to FIGS. **48** to **50**, after removing the first photoresist pattern **10**, processes substantially the same as or similar to those illustrated with reference to FIGS. **15** to **21** may be performed.

An upper portion of the first active fin **402** adjacent the first preliminary gate spacer structure **512** may be etched to form a third recess (not shown). That is, the upper portion of the active fin **402** may be removed using the first dummy gate structure and the first preliminary gate spacer structure **512** on a sidewall thereof as an etching mask to form the third recess. The first offset pattern **502** including silicon dioxide, which may be easily removed in a dry etching process, may be removed, however, the first outgassing reduction or prevention pattern **492** including silicon nitride, which may not be easily removed in a dry etching process, may not be removed but remain. Thus, the first preliminary gate spacer structure **512** may be transformed into a first gate spacer structure **522** including the first diffusion reduction or prevention pattern **462**, the first wet etch stop pattern **472**, the first oxygen-containing silicon pattern **482** and the first outgassing reduction or prevention pattern **492** stacked, for example sequentially stacked.

When the third recess is formed, the first preliminary fin spacer structure **514** adjacent the first active fin **402** may be mostly removed, and only a portion of the first preliminary fin spacer structure **514** may remain and may be referred to as a first fin spacer structure **524**. The first fin spacer structure **524** may include the second diffusion reduction or prevention pattern **464**, the second wet etch stop pattern **474**, the second oxygen-containing silicon pattern **484** and the second outgassing reduction or prevention pattern **494** stacked, for example sequentially stacked. In example embodiments, a height of a top surface of the remaining first fin spacer structure **524** may be equal to or lower than a height of the first active fin **402** under the third recess.

During the dry etching process for forming the third recess, the first offset layer **500** including silicon dioxide may be removed, and thus the spacer layer structure **520** including the diffusion reduction or prevention layer **460**, the wet etch stop layer **470**, the oxygen-containing silicon layer **480** and the outgassing reduction or prevention layer **490** may remain on the second region II of the substrate **400**.

A first source/drain layer **542** may be formed by a selective epitaxial growth (SEG) process using an upper surface of the first active fin **402** exposed by the third recess as a seed.

In example embodiments, the SEG process may be formed by providing a silicon source gas, a germanium source gas, an etching gas and a carrier gas, and thus a single crystalline silicon-germanium layer doped with p-type impurities may be formed to serve as the first source/drain layer **542**. The first source/drain layer **542** may serve as a source/drain region of a PMOS transistor.

During the SEG process, the first outgassing reduction or prevention pattern **492** may be formed on the first oxygen-containing silicon pattern **482** of the first gate spacer struc-

ture **522**, and thus, even if the first oxygen-containing silicon pattern **482** includes, e.g., silicon oxycarbonitride, carbon may be prevented from outgassing from the first oxygen-containing silicon pattern **482**. Additionally, the second outgassing reduction or prevention pattern **494** may cover the second oxygen-containing silicon pattern **484** of the remaining first fin spacer structure **524**, and thus carbon may be prevented from outgassing from the second oxygen-containing silicon pattern **484**.

The spacer layer structure **520** may be formed on the second active fin **404** on the second region II of the substrate **400**, and thus no source/drain layer may be formed by the SEG process.

Referring to FIGS. **51** to **54**, processes substantially the same as or similar to those illustrated with reference to FIG. **44** to **47** may be performed.

First, a growth reduction or prevention layer structure **570** may be formed on the first source/drain layer **542**, the isolation pattern **420**, the first dummy gate structure, the first gate spacer structure **522** and the first fin spacer structure **524** on the first region I of the substrate **400**, and on the spacer layer structure **520** on the second region II of the substrate **400**.

In example embodiments, the growth reduction or prevention layer structure **570** may include a growth reduction or prevention layer **550** and a second offset layer **560** stacked, for example sequentially stacked.

The growth reduction or prevention layer **550** may be formed of, e.g., silicon nitride, and the second offset layer **560** may be formed of, e.g., silicon dioxide.

A second photoresist pattern **20** may be formed to cover the first region I of the substrate **400**, and processes substantially the same as or similar to those illustrated with reference to FIGS. **12** to **14** may be performed to anisotropically etch the spacer layer structure **520** and the growth reduction or prevention layer structure **570** stacked, for example sequentially stacked on the second region II of the substrate **400**.

Thus, a second gate spacer structure **526** and a first growth reduction or prevention pattern structure **576** may be stacked, for example sequentially stacked on each or at least one of opposite sidewalls of the second dummy gate structure in the first direction on the second region II of the substrate **400**, and a second fin spacer structure **528** and a second growth reduction or prevention pattern structure **578** may be stacked, for example sequentially stacked on each or at least one of opposite sidewalls of the second upper active pattern **404a** in the second direction on the second region II of the substrate **400**.

The second gate spacer structure **526** may include a third diffusion reduction or prevention pattern **466**, a third wet etch stop pattern **476**, a third oxygen-containing silicon pattern **486** and a third outgassing reduction or prevention pattern **496** stacked, for example sequentially stacked, and the second fin spacer structure **528** may include a fourth diffusion reduction or prevention pattern **468**, a fourth wet etch stop pattern **478**, a fourth oxygen-containing silicon pattern **488** and a fourth outgassing reduction or prevention pattern **498** stacked, for example sequentially stacked. Additionally, the first growth reduction or prevention pattern structure **576** may include a first growth reduction or prevention pattern **556** and a third offset pattern **566** stacked, for example sequentially stacked, and the second growth reduction or prevention pattern **578** may include a second growth reduction or prevention pattern **558** and a fourth offset pattern **568** stacked, for example sequentially stacked.



A portion of the growth reduction or prevention layer structure **570** on the first region I of the substrate **400** may remain.

Referring to FIGS. **55** to **58**, processes substantially the same as or similar to those illustrated with reference to FIGS. **48** to **50** may be performed.

First, after removing the second photoresist pattern **20**, an upper portion of the second active fin **404** may be etched using the second dummy gate structure, and the second gate spacer structure **526** and the first growth reduction or prevention pattern structure **576** on a sidewall of the second dummy gate structure as an etching mask to form a fourth recess (not shown). The third offset pattern **566** including silicon dioxide, which may be easily removed in a dry etching process, may be removed, however, the first growth reduction or prevention pattern **556** including silicon nitride, which may not be easily removed in a dry etching process, may not be removed but remain. Thus, a third gate spacer structure **586** including the second gate spacer structure **526** and the first growth reduction or prevention pattern **556** stacked, for example sequentially stacked may be formed on the sidewall of the second dummy gate structure.

When the fourth recess is formed, the second fin spacer structure **528** and the second growth reduction or prevention pattern **578** adjacent the second active fin **404** may be mostly removed, and only a portion of the second fin spacer structure **528** may remain. In example embodiments, a height of a top surface of the remaining second fin spacer structure **528** may be equal to or lower than a height of the second active fin **404** under the fourth recess.

During the dry etching process for forming the fourth recess, the second offset layer **560** including silicon dioxide may be removed, and the growth reduction or prevention layer **550** may remain on the first region I of the substrate **400**.

A second source/drain layer **544** may be formed by an SEG process using an upper surface of the second active fin **404** exposed by the fourth recess as a seed.

In example embodiments, the SEG process may be formed by providing a silicon source gas, a carbon source gas, an n-type impurity source gas, an etching gas and a carrier gas, and thus a single crystalline silicon carbide layer doped with n-type impurities may be formed to serve as the second source/drain layer **544**. Alternatively, the SEG process may be formed by providing a silicon source gas, an n-type impurity source gas, an etching gas and a carrier gas, and thus a single crystalline silicon layer doped with n-type impurities may be formed to serve as the second source/drain layer **544**. The second source/drain layer **544** may serve as a source/drain region of an NMOS transistor.

During the SEG process, the third outgassing reduction or prevention pattern **496** may be formed on the third oxygen-containing silicon pattern **486** of the second gate spacer structure **526**, and thus, even if the third oxygen-containing silicon pattern **486** includes, e.g., silicon oxycarbonitride, carbon may be prevented from outgassing from the third oxygen-containing silicon pattern **486**. Additionally, the fourth outgassing reduction or prevention pattern **498** may cover the fourth oxygen-containing silicon pattern **488** of the remaining second fin spacer structure **528**, and thus carbon may be prevented from outgassing from the fourth oxygen-containing silicon pattern **488**.

The growth reduction or prevention layer **550** may be formed on the first active fin **402** in the first region I of the substrate **400**, and thus no source/drain layer may be formed by the SEG process.

Referring to FIGS. **59** to **62**, processes substantially the same as or similar to those illustrated with reference to FIGS. **22** to **27** may be performed.

First, an insulation layer **620** may be formed on the substrate **400** and the isolation pattern **420** to cover the second dummy gate structure, the second gate spacer structure **526**, the second fin spacer layer structure **528**, and the second source/drain layer **544** to a sufficient height, and may be planarized until upper surfaces of the first and second dummy gate electrodes **442** and **444** of the respective first and second dummy gate structures may be exposed.

In the planarization process, the first and second dummy gate masks **452** and **454** may be removed.

A space between the merged first source/drain layers **542** and the isolation pattern **420** and a space between the merged second source/drain layers **544** and the isolation pattern **420** may not be filled with the insulation layer **620**, and thus first and second air gaps **622** and **624** may be formed, respectively.

The exposed first and second dummy gate electrodes **442** and **444** and the first and second dummy gate insulation patterns **432** and **434** thereunder may be removed to form a first opening **632** exposing an inner sidewall of the first gate spacer structure **522** and an upper surface of the first active fin **402**, and to form a second opening **634** exposing an inner sidewall of the second gate spacer structure **524** and an upper surface of the second active fin **404**.

The first and second dummy gate electrodes **442** and **444** and the first and second dummy gate insulation patterns **432** and **434** thereunder may be removed by a dry etching process and a wet etching process, and the first and third diffusion reduction or prevention patterns **462** and **464** may be at least partially removed to expose the first and third wet etch stop patterns **472** and **476**, respectively. However, the first and third wet etch stop patterns **472** and **476** may not be easily remove in the wet etching process, and thus may remain. Accordingly, the first and second gate spacer structures **522** and **524** may not be damaged.

Portions of the first and third diffusion reduction or prevention patterns **462** and **466** on sidewalls of the respective first and third wet etch stop patterns **472** and **476** may be mostly removed. However, portions of the first and third diffusion reduction or prevention patterns **462** and **466** on upper surfaces of the respective first and second active fins **402** and **404** may not be completely removed but at least partially remain. Accordingly, the first and second source/drain layers **542** and **544** adjacent the respective first and second active fins **402** and **404** may not be exposed by the respective first and second openings **632** and **634**.

Referring to FIGS. **63** to **66**, processes substantially the same as or similar to those illustrated with reference to FIGS. **28** to **30** may be performed to form first and second gate structures **682** and **684** in the first and second openings **632** and **634**, respectively.

The first gate structure **682** may include a first interface pattern **642**, a first gate insulation pattern **652**, a first work function control pattern **662** and a first gate electrode **672** stacked, for example sequentially stacked, and the first gate structure **682** together with the first source/drain layer structure **542** may form a PMOS transistor. The second gate structure **684** may include a second interface pattern **644**, a second gate insulation pattern **654**, a second work function control pattern **664** and a second gate electrode **674** stacked, for example sequentially stacked, and the second gate structure **684** together with the second source/drain layer structure **544** may form an NMOS transistor.



Up to now, after the PMOS transistor is formed on the first region I of the substrate **400**, the NMOS transistor is formed on the second region II of the substrate **400**, however, the inventive concepts may not be limited thereto. That is, after the NMOS transistor is formed on the first region I of the substrate **400**, and the PMOS transistor may be formed on the second region II of the substrate **400**.

The first gate spacer structure **522** including the first diffusion reduction or prevention pattern **462**, the first wet etch stop pattern **472**, the first oxygen-containing silicon pattern **482** and the first outgassing reduction or prevention pattern **492** stacked, for example sequentially stacked may be formed on each or at least one of opposite sidewalls of the first gate structure **682** in the first direction, and the growth reduction or prevention layer **550** may be formed on the sidewall of the first gate spacer structure **522** and the first source/drain layer **542**. In example embodiments, at least a portion of the growth reduction or prevention layer **550** adjacent the first gate structure **682** may have a cross-section taken along the first direction of which a shape may be similar to or the same as an "L."

The third gate spacer structure **586** having the second gate spacer structure **526** including the third diffusion reduction or prevention pattern **466**, the third wet etch stop pattern **476**, the third oxygen-containing silicon pattern **486** and the third outgassing reduction or prevention pattern **496** stacked, for example sequentially stacked on each or at least one of opposite sidewalls of the second gate structure **684** in the first direction, and the first growth reduction or prevention pattern **556** on the second gate spacer structure **526** may be formed. In example embodiments, the second spacer structure **526** may have a cross-section taken along the first direction of which a shape may be similar to or the same as an "L," and an inner sidewall and a bottom of the first growth reduction or prevention pattern **556** may be covered by the second gate spacer structure **526**.

Referring to FIGS. **67** to **71**, processes substantially the same as or similar to or the same as those illustrated with reference to FIGS. **31** to **38** may be performed to complete the semiconductor device.

Thus, a capping layer **690** and an insulating interlayer **700** may be formed, for example sequentially formed on the insulation layer **620**, the first and second gate structures **682** and **684**, the growth reduction or prevention layer **550**, and the first and third gate spacer structures **522** and **586**, and first and second contact holes (not shown) may be formed through the insulation layer **620**, the capping layer **690** and the insulating interlayer **700** to expose upper surfaces of the first and second source/drain layer structures **542** and **544**, respectively.

The first and second contact holes may be or may not be self-aligned with the first and third gate spacer structures **522** and **586**, respectively.

After forming a first metal layer on the exposed upper surfaces of the first and second source/drain layer structures **542** and **544**, sidewalls of the first and second contact holes, and the upper surface of the insulating interlayer **700**, a heat treatment process may be performed thereon to form first and second metal silicide patterns **712** and **714** on the first and second source/drain layer structures **542** and **544**, respectively. An unreacted portion of the first metal layer may be removed.

A barrier layer may be formed on upper surfaces of the first and second metal silicide patterns **712** and **714**, the sidewalls of the first and second contact holes, and the upper surface of the insulating interlayer **700**, a second metal layer may be formed on the barrier layer to fill the first and second

contact holes, and the second metal layer and the barrier layer may be planarized until the upper surface of the insulating interlayer **700** may be exposed. Thus, first and second contact plugs **742** and **744** may be formed on the first and second metal silicide patterns **712** and **714**, respectively.

The first contact plug **742** may include a first metal pattern **732** and a first barrier pattern **722** covering a bottom and a sidewall thereof, and the second contact plug **744** may include a second metal pattern **734** and a second barrier pattern **724** covering a bottom and a sidewall thereof.

A wiring (not shown) and a via (not shown) may be further formed to be electrically connected to the first and second contact plugs **742** and **744**.

The above method of manufacturing the semiconductor device may be applied to methods of manufacturing various types of memory devices including spacers on sidewalls of gate structures. For example, the method may be applied to methods of manufacturing logic devices such as central processing units (CPUs), main processing units (MPUs), or application processors (APs), or the like. Additionally, the method may be applied to methods of manufacturing volatile memory devices such as DRAM devices or SRAM devices, or non-volatile memory devices such as flash memory devices, PRAM devices, MRAM devices, RRAM devices, or the like.

The foregoing is illustrative of example embodiments and is not to be construed as limiting thereof. Although a few example embodiments have been described, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the novel teachings and advantages of the inventive concepts. Accordingly, all such modifications are intended to be included within the scope of the inventive concepts as defined in the claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Therefore, it is to be understood that the foregoing is illustrative of various example embodiments and is not to be construed as limited to the specific example embodiments disclosed, and that modifications to the disclosed example embodiments, as well as other example embodiments, are intended to be included within the scope of the appended claims.

What is claimed is:

1. A semiconductor device, comprising:

- an active fin on a substrate;
  - a gate structure on the active fin;
  - a gate spacer structure on a sidewall of the gate structure, the gate spacer structure including a wet etch stop pattern, an oxygen-containing silicon pattern, and an outgassing prevention pattern sequentially stacked,
  - a diffusion prevention pattern configured to prevent a component of the wet etch stop pattern from diffusing into the active fin, the diffusion prevention pattern directly contacting an upper surface of the active fin and a bottom of the wet etch stop pattern, and the diffusion prevention pattern being a single layer; and
  - a source/drain layer on at least a portion of the active fin adjacent the gate spacer structure;
- wherein the gate structure includes an interface pattern, a gate insulation pattern, a work function control pattern, and a gate electrode sequentially stacked on the substrate, and
- wherein the interface pattern protrudes toward the gate spacer structure from other portions of the sidewall of the gate structure.



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2. The semiconductor device of claim 1, wherein the wet etch stop pattern and the outgassing prevention pattern include silicon carbonitride and silicon nitride, respectively.

3. The semiconductor device of claim 1, wherein the oxygen-containing silicon pattern includes silicon oxycarbonitride, silicon dioxide and/or silicon oxynitride. 5

4. The semiconductor device of claim 3, wherein the oxygen-containing silicon pattern includes silicon oxycarbonitride, and wherein the outgassing prevention pattern prevents a component of the oxygen-containing silicon pattern from outgassing. 10

5. The semiconductor device of claim 1, wherein at least one of the wet etch stop pattern and the oxygen-containing silicon pattern has a cross-section taken along a direction, the cross-section having an L-like shape. 15

6. The semiconductor device of claim 1, wherein the wet etch stop pattern directly contacts the sidewall of the gate structure.

7. The semiconductor device of claim 1, wherein the active fin extends in a first direction substantially parallel to an upper surface of the substrate, the gate structure extends in a second direction crossing the first direction, and the gate spacer structure is formed on at least one of opposite sidewalls of the gate structure in the first direction. 20

8. The semiconductor device of claim 1, wherein the outgassing prevention pattern prevents a component of the oxygen-containing silicon pattern from outgassing. 25

9. The semiconductor device of claim 1, wherein the diffusion prevention pattern includes silicon nitride.

10. A semiconductor structure, comprising: 30  
 at least one active fin on a substrate;  
 a gate structure on the at least one active fin;  
 a gate spacer structure on a sidewall of the gate structure,  
 the gate spacer structure being configured to reduce

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outgassing of carbon, the gate spacer structure including a first portion extending in a first direction and a second portion extending in a second direction, and further including a wet etch stop pattern and an oxygen-containing silicon pattern in contact with each other in the first portion and in the second portion; and

a source/drain layer on at least a portion of the at least one active fin adjacent the gate spacer structures;

wherein the gate structure includes an interface pattern, a gate insulation pattern, a work function control pattern, and a gate electrode sequentially stacked on the substrate, and

wherein the interface pattern protrudes toward the gate spacer structure from other portions of the sidewall of the gate structure.

11. The semiconductor structure of claim 10, wherein the gate spacer structure further comprises an outgassing reduction pattern, the wet etch stop pattern, the oxygen-containing silicon pattern and the outgassing reduction pattern being in a stacking configuration.

12. The semiconductor structure of claim 11, wherein the oxygen-containing silicon pattern comprises at least one of a silicon oxycarbonitride layer, a silicon dioxide layer and a silicon oxynitride layer.

13. The semiconductor structure of claim 11, wherein the wet etch stop pattern and the outgassing reduction pattern comprise at least a silicon carbonitride layer and at least a silicon nitride layer, respectively.

14. The semiconductor structure of claim 10, wherein the gate spacer structure includes a diffusion prevention pattern, the diffusion prevention pattern including silicon nitride.

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